Chapter 1

European hake (*Merluccius merluccius*) in the Northeast Atlantic Ocean

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1.1 Distribution

The European hake (*Merluccius merluccius*) is widely distributed over the Northeast Atlantic shelf. Its range extends from Mauritania to off the western coast of Norway (between 21°N and 62°N) and the waters south of Iceland (Casey and Pereiro, 1995), being more abundant from the British Isles to the south of Spain (ICES, 2008). It is also found in the Mediterranean and Black Sea (Casey and Pereiro, 1995). *M. merluccius* is a demersal and pelagic species; it lives mostly between the depths of 70 and 370 m, although it is found in both shallower and deeper waters, from coastal waters (30 m) down to the depths of 1000 m (Lloris *et al.*, 2003; Meiners, 2007).

The spatial behaviour of *M. merluccius* is strongly linked to its biology. Mature fish aggregate during their spawning season (Casey and Pereiro, 1995; Poulard, 2001) over the continental shelf slope from Portugal to Scotland. Besides, there is a northward displacement of mature fish, followed by a coastward displacement of the peak of spawning, as the season progresses along the French waters (Álvarez *et al.*, 2004). This general pattern of distribution is consistent with previous data available on *M. merluccius* spawning periodicity (Arbault and Lacroix-Boutin, 1969; Solá and Franco, 1985; Valencia *et al.*, 1989; Motos *et al.*, 2000). The area around the shelf edge appears as a preferred region for spawning, the shelf break being a natural barrier for spawning of this species. Individuals of *M. Merluccius* appear to be dispersed during non-spawning season (Drouineau *et al.*, 2010). In Portuguese continental waters, the abundance of small individuals of *M. merluccius* is higher in autumn and early spring. In the Southwest area, main concentrations of *M. merluccius* occur at 200–300 m depths, while in the South, they are mainly distributed at coastal waters. In the north of Portugal, juveniles are more abundant between 100 and 200 m depths. In contrast, northern juveniles concentrate in two main nursery areas: the Grande Vasière in the Bay of Biscay and the continental shelf of the Celtic Sea (Álvarez *et al.*, 2001, 2004; Kacher and Amara, 2005).

Depth preferences also vary throughout the life of the individuals of *M. merluccius* showing an ontogenetic distribution pattern (Woillez *et al.*,

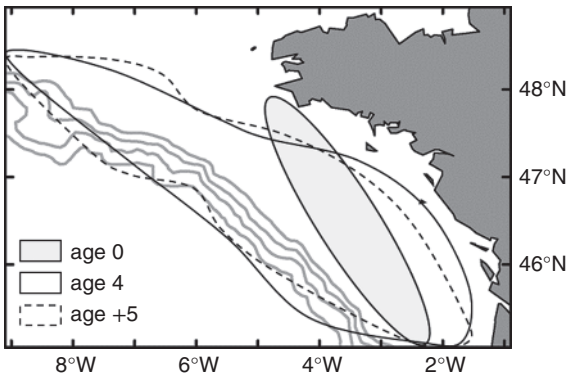

Figure 1.1 Preferential distribution of *M. merluccius* individuals of age 0, 4 and 5 years for the period 1987–2004 (adapted from Woillez et al., 2007). (*Source*: Woillez *et al.* 2007. Reproduced with permission of authors and ICES.)

2007). Vertical distribution of *M. merluccius* eggs and larvae from the northern Bay of Biscay and Celtic sea shelf-edge region shows an occurrence down to 150 m depth with a sub-surface peak of larvae at about 50–60 m depth (Coombs and Mitchell, 1982). The maximum egg abundance occurs close to the isobaths of 200 m depth (Motos *et al.*, 2000). Larvae of *M. merluccius* remain resident in plankton about 2 months in depths from 50 to 150 m until they metamorphose to the juvenile stage (Motos *et al.*, 1998). Individuals of age 0 years concentrate almost exclusively between 75 and 125 m depths, whereas individuals of *M. merluccius* of ages 1 and 2 years are found in shallower waters on the shelf (25–125 m depth), but a fraction of older fish is distributed on the slope at 200–500 m depths (Figure 1.1) (Woillez *et al.*, 2007). Moreover, young individuals of *M. merluccius* (age 0 and 1 years) prefer muddy beds on the continental shelf, while large adults are found on the shelf slope where the bottom is rough and associated with canyons and cliffs (Murua, 2010).

1.1.1 Distribution change

Despite its wide distribution, *M. merluccius* is not evenly distributed over the Northeast Atlantic continental shelf. Furthermore, the abundance of individuals of age 0 years in the two main nursery areas varies inter-annually (Figure 1.2 for the period 1997–2007; Figure 1.3 for the period 2007–2012). In the Celtic Sea, the inter-annual variation in abundance of individuals of age 0 years of *M. merluccius* is higher, whereas concentration of *M. merluccius* over the French continental shelf does not significantly change over time (except for 1998, 1999 and 2003). Sánchez and Gil (2000) reported that in Galician–Cantabrian Sea, nursery areas remained stable and extent independently on the inter-annual density variability. Individuals of age 1 years remain on nursery grounds until spring. Afterwards, some seasonal displacement is detected in individuals of age 2, 3 and 4 years. Younger hakes

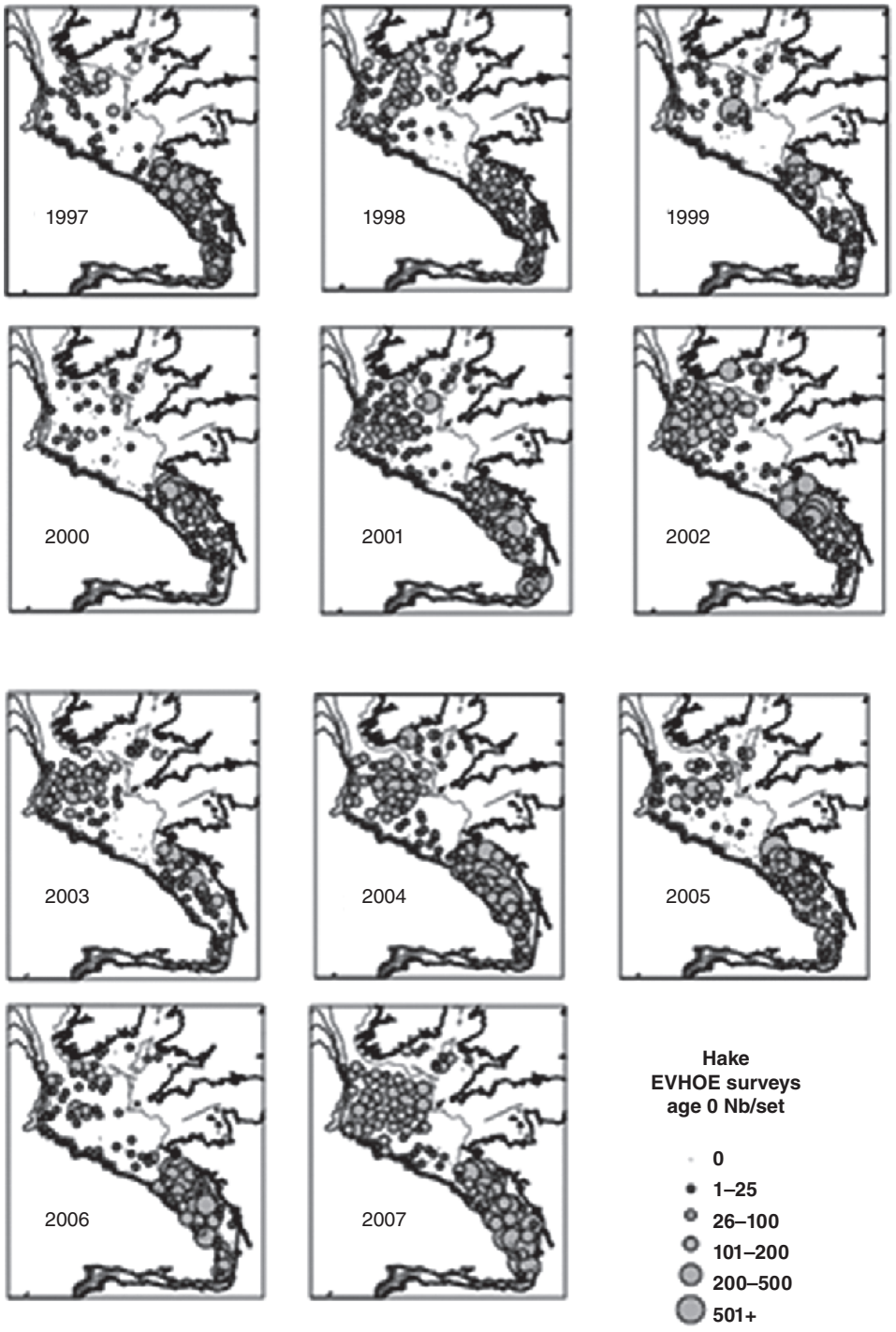

Figure 1.2 Spatial distribution of individuals of age 0 years in *M. merluccius* in the two main nursery areas (Bay of Biscay and Celtic Sea) from 1997 to 2007 (ICES, 2008). (*Source*: ICES 2008. Reproduced with permission of ICES.)

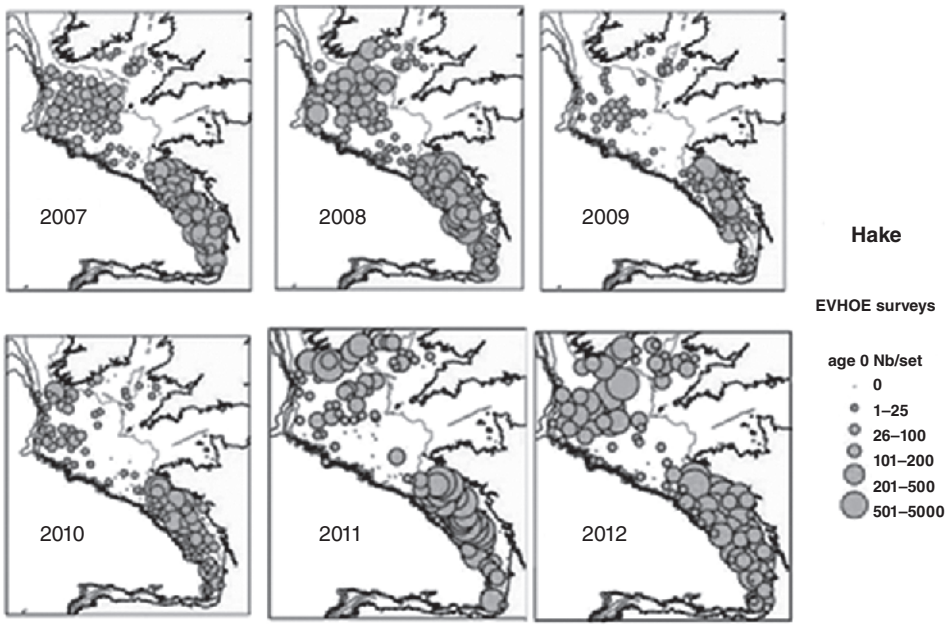

Figure 1.3 Spatial distribution of individuals of age 0 years in *M. merluccius* in the two main nursery areas (Bay of Biscay and Celtic Sea) from 2007 to 2012 (ICES, 2013). (*Source*: ICES 2013. Reproduced with permission of ICES.)

(age of 2 and 3 years) are preferentially found in shallow waters in spring and scattered over the shelf in autumn.

1.2 Physical environment and hydrography

The hydrography of the Northeast Atlantic Ocean is affected by the North Atlantic current, which is a warm ocean current that carries the Gulf Stream northeast towards the European coast (OSPAR Commission, 2000). The North Atlantic current splits into two branches around west Ireland. While the Canary current takes a southerly direction, the other warm-water branch continues north along the coast of northwestern Europe, heating the cold northern atmosphere.

In the North Atlantic Ocean, two major zonally orientated water masses are found. In general, the water masses in the upper layer (down to 1000 m depth) are characterised by Northeast Atlantic Central Water (ENACW), with temperatures ranging between 10.5 and 12°C and salinity between 35.45 and 35.75 (Koutsikopoulos and Le Cann, 1996; Valencia and Franco, 2004). Two sources of ENACW masses are identified in this area: colder water mass with a sub-polar origin (ENACWp) and warmer water mass with sub-tropical origin (ENACWt) (Ríos *et al.*, 1992). Upper waters are influenced by seasonal variations in the atmosphere, whereas below 1000 m, the oceanic waters are

characterised by the Mediterranean Sea overflow water, which spreads into the Northeast Atlantic Ocean from the Gibraltar Strait. It moves northwards from the Portuguese continental slope, entering the Bay of Biscay (Lavin *et al*., 2006). Most of the water masses of the Bay of Biscay and the Atlantic coast of the Iberian Peninsula are the result of a mixture of North Atlantic water masses and waters of Mediterranean Sea origin (OSPAR Commission, 2000).

The oceanic circulation in the Bay of Biscay is characterised by weak clockwise circulation (Figure 1.4), with a mean geostrophic current of about 1–2 cm/s at a depth of 4000 m (Koutsikopoulos and Le Cann, 1996). However,

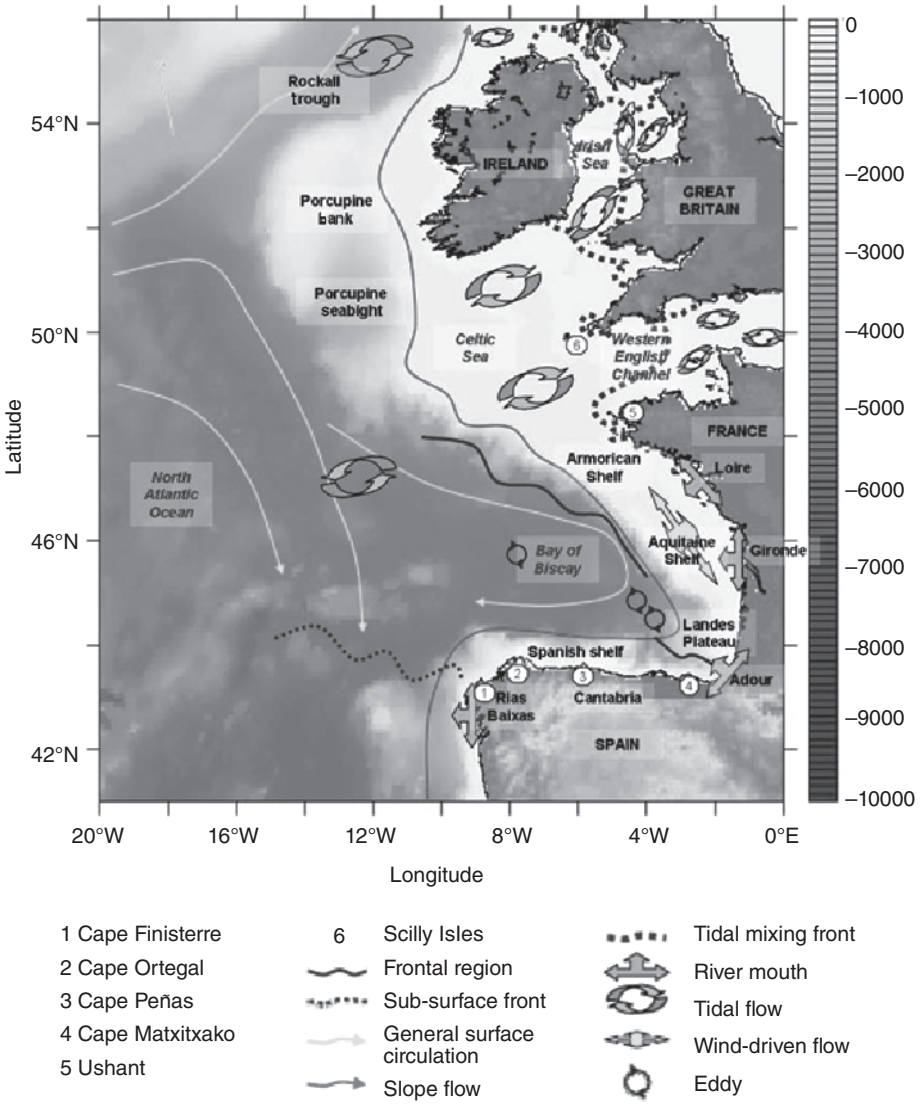

Figure 1.4 Main physical features in the Celtic Sea and the Bay of Biscay (after Mason *et al.*, 2006). (*Source*: Mason *et al.* 2006. Reproduced with permission of IPMA.)

while the deep regions of the bay might be influenced primarily by general oceanic circulation, the shelf is characterised by the dominance of mesoscale structures, which are strongly influenced by regional or local hydroclimatic conditions (Planque *et al*., 2003). Slope currents in the Bay of Biscay show a consistent poleward transport (Pingree and Le Cann, 1990). Instead, the currents over the shelf are mainly driven by wind, buoyancy and tides.

In addition to the general clockwise circulation, and depending on the season, the circulation can become cyclonic along the Portuguese, Galician and northern Spanish and French continental slopes due to the slope current. In winter, when the northerly wind component relaxes, a warm and saline polewards surface flow (ENACWt) takes place at 20–30 m/s off the Iberian Peninsula, moving eastwards along the Cantabrian coast to enter into the Bay of Biscay (Figure 1.4). As this warm water usually reaches the Bay of Biscay near Christmas, it has been referred to as the Navidad or Christmas current (Pingree and Le Cann, 1992). Moreover, in winter, clockwise and anticlockwise eddies are formed in the continental slope due to the interaction between the slope current and topography. These eddies are named 'swoddies' (slope water oceanic eddies) (Pingree and Le Cann, 1992).

On the French coast, the general northerly wind circulation over the shelf produces upwelling (Mason *et al*., 2006). A cold (<12°C) and relatively homogeneous (<12°C) water mass appears below the thermocline. It is formed in April over the French shelf and reaches the coastal region in May. The coastal upwelling off the Galician and Portuguese coasts starts to appear in late spring and reaches the maximum in summer. The result of such upwelling events is the enrichment of the surrounding waters due to the upwelled cool and nutrient-rich waters.

In the Celtic Sea, a persistent poleward-flowing slope current is present along the entire length of the ocean boundary (Figure 1.4). At the surface, along the length of the shelf break, a region of cooler water occurs. It is thought to be a consequence of an internal tide, generated at the 200-m contour, which propagates both onto the shelf and into the ocean. This results in the mixing of cooler, nutrient-rich waters to the sea surface, leading to the potential enhancement of phytoplankton production (Mason *et al*., 2006).

1.3 Life history

1.3.1 Reproduction biology

In Galician and Bay of Biscay waters, females of *M. merluccius* mature at 45–50 cm of total length and males at about 35 cm (Martin, 1991; Lucio *et al*., 2000; Piñeiro and Saínza, 2003). Dominguez-Petit *et al*. (2008) showed that there was a decline of about 10–15 cm, depending on areas and years, in the mean size at maturity observed in the Bay of Biscay and Galician waters, which was related to fishing mortality, different stock biomass levels and environmental conditions.

The reproductive biology of females of *M. merluccius* indicates that this species is a batch spawner (Pérez and Pereiro, 1985; Sarano, 1986; Murua *et al*., 1998), with several batches within the main reproductive season, which has been identified from December to July along the shelf edge of the Galician Coast and the Bay of Biscay to the south-west of Ireland (Martin, 1991; Lucio *et al*., 2000; Piñeiro and Saínza, 2003, Álvarez *et al*., 2004). However, more recent investigations have shown that the spawning season of *M. merluccius* is very protracted on the Galician Coast, in the Bay of Biscay and Mediterranean Sea; that is, spawning activity is observed all year round, although the main spawning season is observed from January to March in the Bay of Biscay and on the Galician shelf, with a secondary peak in June/July for the Galician area (Recasens *et al.,* 1998; Murua and Motos, 2006; Murua *et al*., 2006; Domínguez-Petit, 2007; Korta *et al*., 2010a) (Figure 1.5). This protracted spawning season has been the longest spawning period reported for species of the genus *Merluccius*. The long spawning period has also been found for *M. capensis* (Bianchi *et al*., 1993).

Females of *M. merluccius* are characterised by asynchronous oocyte development, that is, oocytes of all stages are simultaneously present in reproductively active ovaries, and by indeterminate-type fecundity (Murua *et al*., 1998; Murua and Motos, 2006; Korta *et al*., 2010b). Annual fecundity of females should be estimated from the number of oocytes released per spawning (batch fecundity), the percentage of spawning females per day (spawning frequency) and the extension of the spawning season (Hunter *et al*., 1985; Murua *et al*., 2003). The fecundity indeterminacy of hake can be explained by income breeder strategy of the species, that is, it adjusts its food intake with breeding, with a minor reliance on energy stores (Domínguez-Petit and Saborido Rey, 2010).

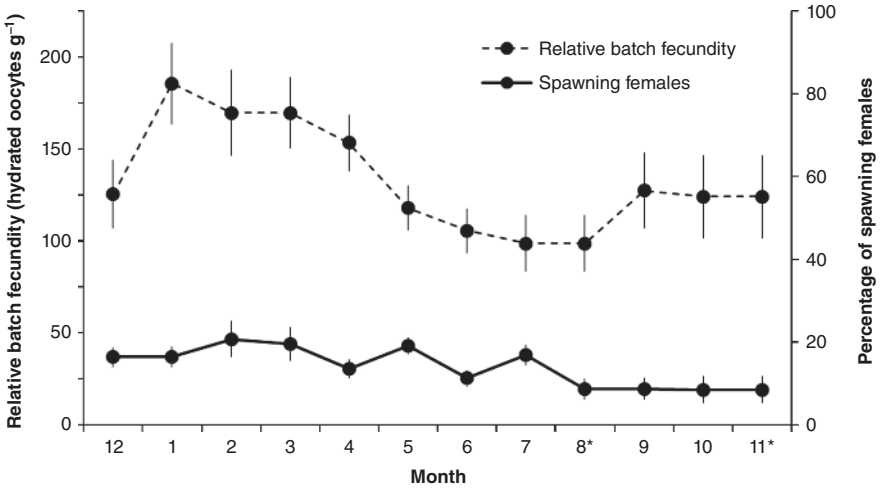

Figure 1.5 Monthly spawning fraction and relative batch fecundity (adapted from Murua *et al*., 2006). *: where estimates of either batch fecundity or spawning fraction were missing, the values were taken from the previous month (July and October, respectively). (*Source*: Murua *et al*., 2006. Reproduce with permission of authors and Wiley.)

Spawning fraction, defined as the percentage of spawning females per day, has been estimated to range from 0.085 to 0.207 in the Bay of Biscay in 1996/1997, which is equivalent to a batch interval of 5–12 days (Murua and Motos, 2006), being highest at the peak of spawning from January to March (5-day batch interval), decreasing afterwards with the advance of the spawning season (batch interval of about 12 days). Mature female individuals of *M. merluccius* in the Galician shelf spawn with a batch interval of about 5 days from January to March, decreasing afterwards to about 10 days (Domínguez-Petit, 2007).

Moreover, the relative batch fecundity in females of *M. merluccius* varies significantly between months and years, but not between different areas within the Bay of Biscay (Murua *et al.*, 2006). Two levels of relative batch fecundity were estimated for 1997: the highest from January to April (average: 167 eggs per gram gutted female) and the lowest from May to October (average: 112 eggs per gram gutted female).

1.3.2 Diet

Small individuals of *M. merluccius* feed primarily on crustaceans living on the bottom, while adults are mostly piscivorous (Olaso, 1990; Olaso *et al.*, 1994; Preciado *et al.*, 2008). This shift in the feeding habits is the result of ontogenetic changes due to food requirements and bathymetrical migrations (Sánchez and Gil, 2000). Hake's foraging strategy has been observed to be similar to that of ambush predators (Kacher, 2004), searching for preys close or away from the bottom. The main preys of *M. merluccius* are actively swimming species such as horse mackerel (*Trachurus trachurus*), anchovy (*Engraulis encrachicolus*), pilchard (*Sardina pilchardus*) and blue whiting (*Micromesistius poutassou*) (Casey and Pereiro, 1995). A positive correlation between predator size and prey size was found, with small individuals of *M. merluccius* preying on small clupeids, while large individuals of *M. merluccius* feeding on large demersal prey (Guichet, 1995; Velasco and Olaso, 1998).

The number of prey taxa decreases during ontogenesis, indicating a tendency to less generalised feeding as individuals of *M. merluccius* grow (Mahe *et al.*, 2007). Du Buit (1996) reported that *M. merluccius* is an opportunistic consumer, but recent studies suggest selective feeding behaviour (Mahe *et al.*, 2007), as it appears to have some preference to an alternative prey that may be equally or more available. This selection could stem not only from suitable size, but also from higher energy content species or physiological traits (López-López *et al.*, 2012).

Individuals of *M. merluccius* appear to show feeding plasticity between neighbouring areas, depending on both the continental shelf and the availability of prey. In areas with abrupt bathymetry, that is, the Cantabrian shelf, *M. merluccius* is distributed deeper in the water column. Here, the encounter rate with prey species (horse mackerel, sardine and small hake) inhabiting shallower waters decreases, favouring predation on blue whiting (*M. poutassou*) (Velasco and Olaso, 1998). Large individuals of *M. merluccius* can feed on small hake, but this cannibalistic behaviour changes with the

spatial distribution of predator and prey. In the north of the Bay of Biscay and Celtic Sea, nursery grounds are documented, which may lead to cannibalism being more prevalent than in the south of the Bay of Biscay, where the spatial overlap between juveniles and adults is lower (Kacher and Amara, 2005). It becomes rare along the Portuguese waters (Cabral and Murta, 2002), probably conditioned by the steep continental shelf.

Seasonality on diet also exists. Individuals of *M. merluccius* eat fish in all quarters of the year (Guichet, 1995), and then the diet composition shows little variation. However, feeding rate increases in the second quarter, mainly in older individuals of *M. merluccius*. This pattern could be related to recovery from spawning season (Velasco and Olaso, 2000).

No information about larval diet is known for North Atlantic hake. However, for Mediterranean hake, Morote *et al*. (2011) found that larvae presented a clear preference for adult calanoid copepods and they foraged even at low light intensity.

1.3.3 Growth

Growth is a process that is related with a period of time, that is, age. That is why most of the studies on hake growth are based on the observation of otolith. Different technical approaches are documented on age interpretation from otolith (De Pontual *et al*., 2006). Therefore, growth estimation may vary depending not only on biological and geographical diversity, but also on methodological aspects or the combination of all of them (Piñeiro and Saínza, 2010).

Attending to the macrostructure (annual scale) of otolith in adults of *M. merluccius*, the growth rate indicates a slow growth (Piñeiro *et al*., 2009). However, when analysing the microstructure (daily scale) in juveniles of this species, the growth rate supports a rapid growth (Piñeiro *et al*., 2008) (Figure 1.6). Small larvae of *M. merluccius* (until 20 days old) are characterised by a constant low growth rate (0.14 mm/day) and a big mouth width (Álvarez and Cotano, 2005). Recent larval studies on the Galician shelf reported lightly higher growth rates of 0.20 and 0.15 mm/day in winter and summer, respectively (CRAMER, 2012).

The first annual ring is particularly difficult to distinguish in otolith of *M. merluccius*, mainly due to its reproductive strategy. Females of *M. merluccius* spawn during a protracted spawning season, which makes recruits of different size belong to the same year. This leads to great variability in the growth pattern of otolith during the first year.

Besides, age estimation from otolith hangs of both low precision and high bias (Piñeiro *et al*., 2009). Several capture-recapture experiments have been carried out to determine the error due to age estimation. Although recapture rate is low and varies among studies, growth rate is demonstrated to be underestimated by twofold (De Pontual *et al*., 2003; Piñeiro *et al*., 2007). This underestimation of individual growth in *M. merluccius* due to overestimation of age (De Pontual *et al*., 2006) shows that otolith age interpretation method, conventionally accepted and routinely applied, is not valid (ICES, 2010a).

Figure 1.6 Larvae otolith of age 27 days showing daily and sub-daily rings (after CRAMER, 2012). (*Source*: AZTI. Reproduced with the permission of AZTI.)

1.3.4 Mortality

Natural mortality rate during early life stages is assumed to be high. For example, in a review of mortality estimates (Houde and Zastrow, 1993), the mean mortality for marine fish larvae was 21.3% per day. Mortality coefficients estimated by Álvarez and Cotano (2005) for Atlantic hake ranged from 9% to 15% per day for the years 2001 and 2002, respectively. These values are in the lower interval reported for the genus *Merluccius* (Hollowed, 1992; Smith, 1995; Vargas *et al*., 1996; Brown *et al*., 2004).

Limited information is available about natural mortality rates in juveniles and adults of *M. merluccius*. Cannibalism is observed in stomach content ranging from 0% to 30% of total volume, with a mean value of about 5%. Before capture-recapture experiments, natural mortality estimation for age 0 and 1 years is significant, reaching natural mortality values of 1 and 0.5 per year for age 0 and 1 years respectively (ICES, 2009).

Some studies regarding maturation and growth processes suggest that mortality in males could be higher than that in females (Murua, 2006). However, there is also temporal variability, given by the intrinsic variability on intra- and inter-specific predation rates. Cannibalism is a relevant process in areas where juveniles and adults of *M. merluccius* coexist (Velasco, 2007; Mahe *et al*., 2007). The relevance of inter-specific predation on *M. merluccius*

has also been highlighted in some areas. For example, it has been estimated that predation mortality on *M. merluccius* by cetaceans, in the southern Bay of Biscay, could double the natural mortality that is assumed nowadays (Santos *et al.*, 2014).

Hewitt and Hoenig (2005) estimated a relationship between longevity and natural mortality. Natural mortality in *M. merluccius* is assumed to be a constant and equal to 0.4 per year, not 0.2 per year as it was previously considered. The rationale for this high values is found in the fact that individual growth in *M. merluccius* is about two times faster than it was believed. Thus, the longevity in *M. merluccius* is reduced by about half, from age of about 20 years to about 10 years. Tagging experiments developed in the last decade in the Bay of Biscay suggested higher values for mortality, but there are other factors such as extra mortality, due to the tagging itself or the emigration of tagged fish from the region, which may be confounded with natural mortality. This extra mortality might be part of the cause of such relevant differences in longevity (De Pontual *et al.*, 2013).

1.3.5 Horizontal and vertical migration

Migrations of *M. merluccius* have been analysed from the seasonal distribution of reported catches. From the beginning of the year until March/April, adults are present in the north of the Bay of Biscay. They appear on the shelf edge in the Celtic Sea in June and July. Later, from August to December, a large fishery on *M. merluccius* is centred to the west and southwest of Ireland, with a decline in catch in shallower waters (ICES, 2008). Migrations have been found to be mainly linked to reproduction (Persohn *et al.*, 2009). The main spawning area of *M. merluccius* shows a northward displacement as the season advances (Álvarez, *et al.*, 2004), which can be explained by a migration of spawners from south to north. In this regard, some studies on the Galician continental shelf show that individuals of *M. merluccius* carry out seasonal and ontogenetic migrations along the bathymetric gradient (Fariña *et al.*, 1997). Similarly, once the larval pelagic phase is concluded, juveniles of *M. merluccius* actively swim towards the bottom (pre-recruits), starting the recruitment to the nursery areas located over the continental shelf (Sánchez and Gil, 2000).

In addition to seasonal horizontal migrations, individuals of *M. merluccius* have diel vertical movements that bring the fish close to the surface despite the high thermal stratification. De Pontual *et al.* (2012) found that thermocline does not impede hake vertical movements and fish can experience rapid temperature changes of greater than 7°C as they move across highly stratified water layers. Vertical movements have been found to be related to feeding. Individuals of *M. merluccius* live close to the bottom during the daytime, but then, it moves vertically in the water column at night to feed (Cohen *et al.*, 1990; Sánchez and Gil, 1995).

1.4 Population dynamics

ICES identifies two stocks of *M. merluccius* in the Northeast Atlantic Ocean. The northern stock (ICES Division IIIa, Sub-areas II, IV, VI and VII and Divisions VIIIa, b, d) limited by the Norwegian coast, and the southern stock (ICES Divisions VIIIc and IXa) limited by the Gibraltar Strait (ICES, 2013). Between both stocks, the limit is placed in Capbreton Canyon, close to the border between the French and Spanish coasts.

Genetic studies (Plá and Roldán, 1994; Roldán *et al*., 1998) found no evidence of multiple populations of European hake in the Atlantic Ocean. The population structure of *M. merluccius* within the Atlantic Ocean is more complex than the distinct northern and southern stocks described previously. Moreover, Castillo *et al*. (2005) found that there were no genetic differences between both stocks (Divisions VIIIc and VIIIa, b, d). A similar conclusion was reached by Mattiucci *et al*. (2004), who did not find genetic difference within the northern stock of *M. merluccius*, that is, between the Celtic Sea and the Bay of Biscay. More recent studies on population genetics also support previous results (Balado *et al*., 2003; Pita *et al*., 2010, 2014).

1.4.1 Population structure

Due to sexual dimorphism, there is a difference in the growth pattern between both sex that has been associated with the onset of maturity (Recasens *et al*., 1998; Lucio *et al*., 2000). Males attain maturity at a lower size than females do. Consequently, at total length of about 25–45 cm, there is an accumulation of males, and the fraction of mature males is moderately higher than the fraction of mature females (Pérez and Pereiro, 1985; Fariña and Fernández, 1986; Lucio *et al*., 2000; Piñeiro and Saínza, 2003).

Females of *M. merluccius* reach larger size than males. Thus, in the largest length classes, the sex ratio is skewed towards females. In fact, all of the largest individuals of *M. merluccius* are consistently females (Casey and Pereiro, 1995). This growth rate, together with the fact that males reach maturity at a lower size than females (Piñeiro and Saínza, 2003), may suggest that the mortality rate for males is higher than that for females.

1.4.2 Recruitment

Recruitment in *M. merluccius* has been related to environmental factors. High annual recruitments occur during intermediate oceanographic scenarios, and decreasing recruitments are observed in extreme oceanographic situations (Sánchez and Gil, 2000). These recruitment pattern leads to well-defined

patches of juveniles, found in defined areas of the continental shelf. Concentrations of recruits vary in density according to the strength of the year-class.

Recruits (age 0 years) of *M. merluccius* are found in depths from 70 to 200 m, with the highest densities at depth of about 100 m on the continental shelf in the main two nursery areas of the northern stock, that is, at in the north of the Bay of Biscay and in the south-western part of Ireland (Kacher and Amara, 2005).

In the southern Bay of Biscay, over the north and west Iberian Peninsula coast, the highest concentrations of recruits are found between 90 and 180 m depth (Sánchez and Gil, 2000), which represents the biggest nursery area of *M. merluccius* (Casey and Pereiro, 1995). Individuals of age 0 years is recruited during autumn into the stock (Pereiro *et al.*, 1991).

1.4.3 Connectivity between stocks

At present, it is not possible to quantify migrations between northern and southern stocks of *M. merluccius* due to the lack of data. Moreover, connectivity studies are still scarce to provide unequivocal information on population dynamics in *M. merluccius*.

A recent research on *M. merluccius* otolith geochemistry, used as natural tags for connectivity and migration, shows strong ontogenetic signals (Tanner *et al.*, 2012), which provides some evidences for movement of European hake between the local stocks in the Northeast Atlantic Ocean. Movement of individuals among locations has been recorded. In this sense, a number of individuals collected in the Celtic Sea (northern stock) were assigned to the groups dominated by southern stock. The main result is the lack of significant genetic divergences between the northern and southern stocks of *M. merluccius* (Roldán *et al.*, 1998; Castillo *et al.*, 2005; Pita *et al.*, 2011).

1.5 Ecosystem considerations

1.5.1 Role of the species

Both adults and juveniles of *M. merluccius* are considered to be high mean trophic level predators in the West Atlantic Ocean. The mean trophic level of *M. merluccius* in different ecoregions is higher than 4.0. Adults of *M. merluccius*, for example, have higher mean trophic level compared to other similar gadoid species such as cod (*Gadus morhua*) in the Celtic Sea (Chassot *et al.,* 2008) and have a similar mean trophic level of some marine mammals, tunas, harbour porpoises or sharks in the Bay of Biscay (Sánchez and Olaso, 2004; Guénette and Gascuel, 2009; Lassalle *et al.*, 2012). The mean trophic level estimated for *M. merluccius* in the North Sea is lower (Jennings *et al.*, 2002), but still remaining close to levels cited previously. Scarce information is available for the Portuguese coast, but a similar mean trophic niche is assumed (Borges *et al.*, 2004).

1.5.2 Species interaction

Competition for habitat suitability has not been specifically analysed for *M. merluccius*, but studies suggest a potential competition for food with other demersal and/or pelagic predators, playing an important role on the ecosystems. In this sense, it appears that, in the southern Bay of Biscay, adults of *M. merluccius* compete for anchovy (*Engraulis encrasicolus*) with megrim (*Lepidorhombus boscii*), monkfish (*Lophius budegassa* and *L. piscatorius*) and juveniles of hake in autumn, whereas in spring, anchovy might have already achieved a size too large to be an important prey for *M. merluccius* (López-López *et al*., 2012). Anchovy is also one of the most important preys for tuna species as has been shown by Goñi *et al*. (2011) for the Bay of Biscay.

Individuals of *M. merluccius* can also be target prey for top predators on the system. Recent studies show that *M. merluccius* plays a role as preferred prey species for common dolphins (*Delphinus delphis*), that also prey on sardine (*S. pilchardus*) and blue whiting (*M. poutassou*) in the Cantabrian waters (Santos *et al*., 2013), whereas they are classified as secondary prey along the French coast (Meynier *et al*., 2008). Individuals of *M. merluccius* are also preyed upon by stripped dolphins (*Stenella coeruleoalba*), harbour porpoises (*Phocoena phocoena*) and common bottlenose dolphins (*Tursiops truncatus*). It has been estimated that for the southern stock of *M. merluccius,* the mean removal by cetaceans often exceeds hake natural mortality (Santos *et al*., 2014).

1.5.3 Species interaction with environment

Synchronous changes have been observed in recruitment success of *M. merluccius*, which suggests that environmental conditions may play a role (Goikoetxea and Irigoien, 2013). For the southern stock of *M. merluccius*, shifts in environmental regime, using North Atlantic Oscillation index (NAO) and upwelling, may have contributed to a decelerated growth and the later maturation in individuals of *M. merluccius* in the Galician coast (Dominguez-Petit *et al*., 2008). Other studies show that moderate upwelling, together with weak poleward currents (PC), leads to strong recruitments in Galicia and the Cantabrian Sea (Sánchez and Gil, 2000). Moderate water influx of the PC would allow eggs and larvae to remain close to nursery grounds. Mesoscale structures such as eddies appear to retain larvae and juveniles of *M. merluccius* inside their nuclei and favour the feeding behaviour of recruits. A geostrophic vertical forcing provides nutrients to the upper layers and appears to have a positive effect on the abundance and distribution of recruits. In contrast, due to the massive intrusion of warm water in winter and the progressive narrowness of the Cantabrian shelf, eggs and larvae are advected from spawning areas to the open ocean with the subsequent high mortality (Sánchez and Gil, 2000).

The current regime over the French continental shelf also influences early life stages (eggs and larvae) survival in *M. merluccius* (Álvarez *et al*., 2001;

Goikoetxea and Irigoien, 2013). The transport or retention over the nursery areas is a critical process in the life cycle of *M. merluccius* (Parrish *et al*., 1981). Spatial distribution of larvae suggests a movement onshore, where nurseries are located (Álvarez *et al*., 2001, 2004). Likely, the drift of larvae from spawning sites to the nursery areas is associated with physical characteristics of the region, such as wind-induced transport in the Ekman layer, geostrophic currents and/or prevalent winds (Álvarez *et al*., 2001, 2004), and particularly the current regime during spring (Valdés *et al*., 1996; Motos *et al*., 2000).

Inter-annual differences in water temperature are found to result in differences in growth rates in individuals of *M. merluccius* (Álvarez *et al*., 2001, 2004; Kacher and Amara, 2005). Fernandes *et al*. (2010) found a relationship between warm waters and recruitment of *M. merluccius*. Similarly, Goikoetxea and Irigoien (2013) commented that warmer water temperatures could be beneficial for northern stock of *M. merluccius*. A rise in temperature is believed to increase development rate (Ottersen and Sundby, 1995; Fiksen and Slotte, 2002) as well as fish behaviour and metabolism (Murua, 2006; Cury *et al.*, 2008). *M. merluccius* shows to have a preferential temperature range for spawning (10–12.5°C), and larvae have mainly been found in water temperatures of between 10.5 and 13°C (Álvarez *et al*., 2001; Ibaibarriaga *et al*., 2007). Persohn *et al*. (2009) determined different preferential temperature ranges in the Bay of Biscay and in the Celtic Sea.

Environmental dependence is different for adults and juveniles of *M. merluccius*. Juveniles are strongly associated with specific depth ranges. Different depth-areas associations may be related with the feeding habits of recruits in *M. merluccius*, as the zooplankton biomass is relatively higher in those areas (ICES, 2013). In contrast, adults of *M. merluccius* have strong preferences and remain at the same conditions of temperature and/or salinity when environmental variations occur or are randomly distributed with regard to these parameters (Persohn *et al*., 2009).

In addition to water temperature and transport, copepod abundance has also been found to be related to survival (Goikoetxea and Irigoien, 2013). Copepods in the Celtic Sea decreased in abundance, after the regime shift in the late 1980s, in synchrony with the sudden change in hake recruitment success. Similarly, copepod abundance and ocean warming appear to be correlated. However, not all copepod species react in the same manner to ocean warming (Hinder *et al*., 2013). In contrast to *Calanus helgolandicus*, *Calanus finmarchicus* has continued to contract its range over 50 years of warming. *C. finmarchicus* is a key food source for fish such as cod and hake.

In addition to natural fluctuations in the *M. merluccius* abundance, anthropogenic activities can also influence marine population environment and, consequently, interact with species habitat. In November 2002, the 'Prestige' oil spill took place off the Galician coast, causing one of the biggest ecological disasters of the history. The main shelf area contaminated by the oil spill coincides with the main nursery of the southern stock of *M. merluccius* (Casey and Pereiro, 1995; Sánchez and Gil, 2000). Therefore, negative effects could have

been expected for hake stock. However, 3 years after the 'Prestige' oil spill, no clear effect of the event has been detected on both the demersal and pelagic domain of the Iberian shelf (ICES, 2006). There have not been significance effects on the abundance or distribution in juveniles of *M. merluccius* (Sánchez *et al*., 2006). Moreover, the hystopathological analysis undertaken in hake livers of the Bay of Biscay did not show any clear signal of relationship between detected pathologies and the oil spill (Marigómez *et al*., 2006). More recently, Díez *et al*. (2011) found that there were no statistical differences when comparing the fraction of atretic oocytes before and after the 'Prestige' oil spill. They concluded that the fuel spilt from the 'Prestige' did not have a detectable effect over the southern stock of *M. merluccius*.

1.6 Fishery

1.6.1 Northern stock

The main catches of *M. merluccius* of this stock come from the south western European Atlantic waters (Table 1.1). The relative average catches for the period 1971–2012 are 44% in south western Irish waters (ICES Sub-area VII), 41% in French Atlantic waters (ICES Divisions VIIIabd) and 15% in North Sea (Sub-area IV) and Western Scottish waters, jointly (Sub-area VI) (ICES, 2013). This stock is similarly harvested by trawlers, longliners and gillnets (Figure 1.7a). In recent years, the fleet of Spain accounted for the main fraction of landings (∼60%), followed by fleets of France (∼25%) and United Kingdom, Denmark, Ireland, Norway, Belgium, Netherlands, Germany and Sweden (∼15%, jointly). These landings do not reflect the total allowable catch (TAC) allocated to France and Spain, which accounts for 52% and 28%, respectively. The mismatch between TAC allocation and landings is explained by the bilateral agreement signed by France and Spain on quota swaps. By virtue of the Arcachon Agreement (1992, renewed in 2003), Spain transfers a fraction

Table 1.1 Northern and Southern hake stocks average landings in ICES areas between 1972 and 2012

Stock	ICES area	Average landings from 1972 to 2012 (thousand tonnes)
Northern hake stock	North Sea (Sub-area IV) and Western Scottish waters (Sub-area VI)	8.1
	South-western Irish waters (Sub-area VII)	24.7
	French Atlantic waters (Divisions VIIIabd)	22.2
Southern hake stock	Iberian waters (Divisions VIIIc and IXa)	15.3
TOTAL		70.3

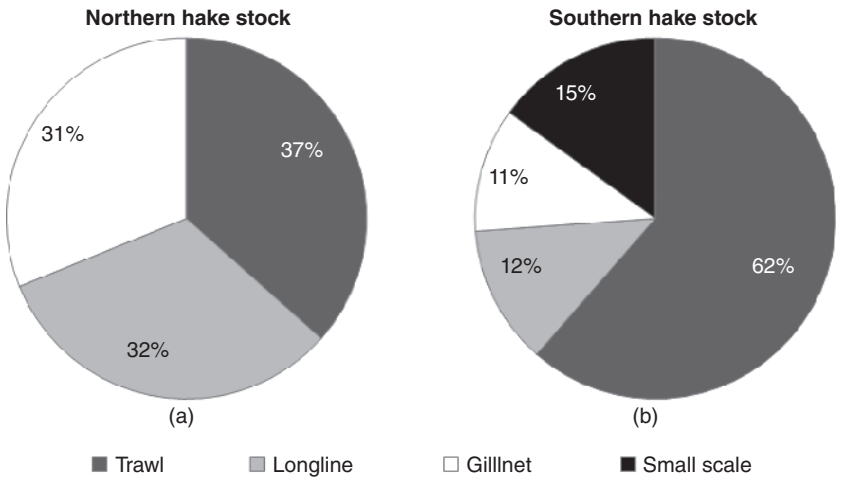

Figure 1.7 Northern and Southern hake stock landings by gear in 2010.

of its anchovy quota in exchange for a fraction of the French participation of quotas on northern hake and other species (Aranda *et al.*, 2006).

Attending to the data reported in 2012 by the Spanish General Secretariat of Fishery, the Spanish catches of *M. merluccius* are mainly harvested in south western Irish waters (69%) and secondly in French Atlantic waters (26%). The remaining 5% is caught in western Scottish waters (ICES Division VI). Harvests are mainly reported by longliners (61%) and trawlers (33%), and the rest by gillneters (6%). Longliners are mainly specialised in a homogeneous fishing activity targeting *M. merluccius* along the continental slope (Castro *et al.*, 2011). The Spanish trawl in south western Irish waters (42% of total Spanish trawl catches) adopts different fishing strategies as follows: bottom otter trawl targeting megrim (*Lepidorhombus whiffiagonis*) on the continental shelf, using 80-mm mesh size, and bottom otter trawlers operating on the slope targeting both hake (100-mm mesh size) and Norway lobster (*Nephrops norvegicus*; 80-mm mesh size) (Castro *et al.*, 2012). The Spanish trawl fleet harvesting in the French Atlantic waters is basically a bottom pair trawl fleet (47% of total Spanish trawl catches). From 2007 to 2012, there was a reduction in 47% of the Spanish trawl capacity, which highlighted the observed increase in the longline activity in recent years. The mean sizes of *M. merluccius* harvested by the Spanish fleet operating in the French Atlantic waters hang on the fishing strategy, that is, fish greater than 60 cm of total length in longline and gillnet landings and fish less than 40 cm in bottom pair trawlers.

In 2012, the French catches are mainly taken in French Atlantic waters (48%) and secondly in south western Irish waters (38%). Catches were basically reported by gillnets (57%), trawlers (19%) and longliners (14%). Gillnetters harvest similar amount of *M. merluccius* in both areas. However, different minimum mesh sizes for fixed gears in both areas, that is, 120 mm for ICES

Sub-area VII and 100 mm for ICES Divisions VIIIabd, are established (European Commission, 2001). French trawlers report higher landings in the North Sea. The mean size of *M. merluccius* at landings is similar among French fishing strategies (>55 cm of total length), except for trawlers that are specialised in the exploitation of Norway lobster in the Grande Vasière (ICES Division VIIIabd), with the lowest mean size of 39 cm in the harvested fish.

1.6.2 Southern stock

The southern stock of *M. merluccius* comprises the Atlantic coast of Iberian Peninsula, corresponding with the Atlantic Spanish and Portuguese waters (ICES Divisions VIIIc and IXa). This stock is basically exploited by Spanish (68% of landings) and Portuguese fleets (32% of landings) for the period 1972–2012 (ICES, 2013), which is in agreement with the European Union TAC allocation. Landings are mainly due to trawlers (62%), highly above longliners or gillneters.

In 2010, the Spanish landings of hake come from trawlers, gillnetters, longliners and artisanal fisheries (Figure 1.7b). The Spanish trawl fleet (46% of Spanish hake landings) consists of pair bottom trawlers (28%), which exploits hake together with blue whiting (*M. poutassou*) (Castro *et al*., 2010) and two different bottom otter trawl strategies (18% of landings) (ICES, 2013). One of them is specialised in targeting demersal fish, while the other one is mainly directed at pelagic fish (Punzon *et al*., 2010). The longline fleet (21% of landings) uses a mixed fishing strategy because it also exploits other demersal fish as conger (*Conger conger*) and sea bream (*Pagellus bogaraveo*). The gillnet (16% of landings) uses specific nets when targeting hake ('*volanta*', with a 90-mm mesh size). Finally, north western Spanish artisanal fleet gives similar landings of *M. merluccius* than the whole fishing activity in the Gulf of Cadiz. The length composition of *M. merluccius* at landings due to the trawl fleet, since the implementation of the minimum landing size in 1991, has a mode of about 29–31 cm of total length, which hangs on the year. Portuguese landings of *M. merluccius* are mainly made by the artisanal fleet (average: 65% along 1972–2012), followed by the mixed-species trawl fleet (35%), which catches *M. merluccius* together with other fish species and crustaceans such as horse mackerel (*T. trachurus*), anglerfish (*L. budegassa* and *L. piscatorius*), four-spot megrim (*L. boscii*), mackerel (*Scomber scombrus*), Spanish mackerel (*Scomber colias*), blue whiting (*M. poutassou*), red shrimp (*Aristeus antennatus*), rose shrimp (*Parapenaeus longirostris*) and Norway lobster (*N. norvegicus*). The Portuguese artisanal fleet is allowed to use different gears in the same trip. So, it is not possible to differentiate catches by gear for this fleet. However, the trawl fleet can be split in two: the trawl fleet targeting demersal fish (70-mm mesh size) and the trawl fleet targeting crustaceans (55-mm mesh size). The first one operates at 100 and 200 m depths along the entire Portuguese coast, while the second one operates in deeper waters (100–750 m depth), mainly in the south-west and south areas. The core of the fishing season is from May to October in both fleets.

1.7 Assessment

The assessment of *M. merluccius* is carried out separately for northern and southern stocks. Before 2010, both stocks were assessed using age-structured stock assessment models. For the northern stock was used the Extended Survivors Analysis, XSA (Shepherd, 1999; ICES, 2009), and for the southern stock was used a Bayesian Virtual Population Analysis, VPA (ICES, 2009). In both cases, age–length keys were used to transform length data to age data. Tagging programs carried out in the year 2003 in the Bay of Biscay have shown evidence of underestimation of individual growth in *M. merluccius* being half of that derived from otolith age interpretation method (De Pontual *et al*., 2006). Later, it was confirmed by a tagging program carried out in the Iberian Peninsula (Piñeiro *et al*., 2007). Thus, in 2010, the assessment models of both stocks were replaced by length-structured models, the Stock Synthesis model (SS3) for the northern stock (ICES, 2010b; Methot and Wetzel, 2013) and the Globally Applicable Area Disaggregated General Ecosystem Toolbox (GADGET) for the southern stock (Begley and Howell, 2004; ICES, 2010b).

The von Bertalanffy growth model (von Bertalanffy, 1938) was used to model individual length growth, and maximum total length was fixed to 130 cm in both stocks of *M. merluccius*. The growth rate was internally estimated by the models, and the age at which the individuals would have had zero length was set to 0 in the case of southern stock. The growth rate internally estimated by the models was similar for both stocks. Natural mortality was assumed to be equal to 0.4 per year. Some scientific surveys on *M. merluccius*, from several countries in the study area, were used in the calibration of the assessment models.

1.7.1 Northern stock

Since 2010, the northern stock of *M. merluccius* is assessed using SS3 (Methot and Wetzel, 2013), which is a flexible statistical age-structured modelling framework. It can vary from a simple production model to a complex age–length-structured model with spatial explicit resolution. In the specific implementation of northern stock of *M. merluccius*, the model configuration has quarterly time steps. It is assumed that recruitment occurs all along the year with variable proportion by season. The exploitation is split by fleet, and it is characterised by their fishing gears.

The input data of *M. merluccius* comprises biological parameters, such as maturity and weight at length, landings, discards and abundance indices. Mean weight at total length is calculated from the following length (L; cm)–weight (W; g) relationship (ICES, 1991):

$$W = 0.00513 * L^{3.074}$$

The spawning stock biomass (SSB) for sex combined is used as proxy of stock's reproductive potential. The time-invariant logistic maturity ogive used is L_{50} = 42.85 cm and slope = −0.2 (ICES, 2010b). For landings, discards

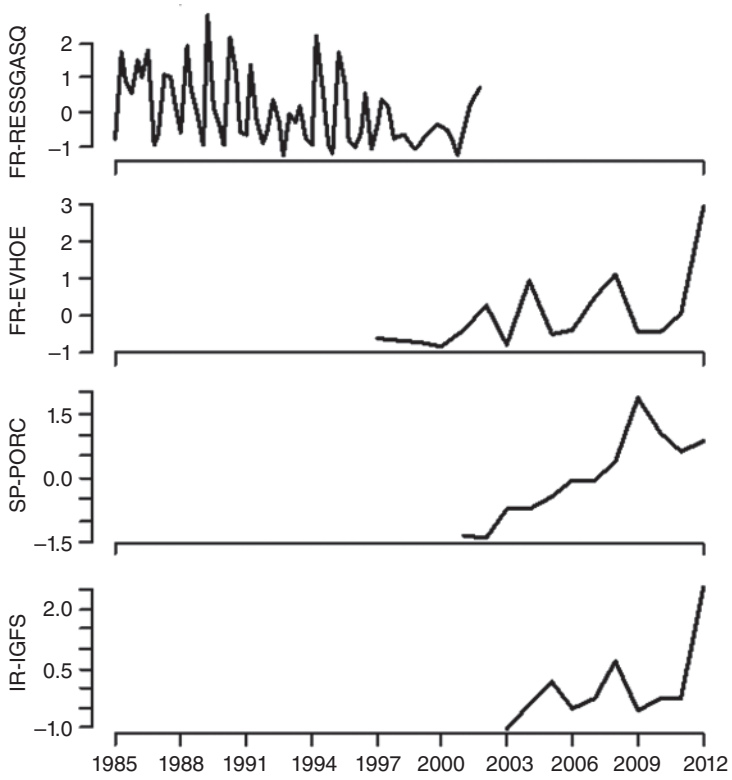

Figure 1.8 Time series of four abundance indices used to calibrate the assessment model of northern stock of European hake. The acronyms correspond to French surveys in the Bay of Biscay (FR-RESSGACQ) and in the Bay of Biscay and Celtic Sea (FR-EVHOE); Spanish survey in the Porcupine Bank (SP-PORC) and the Irish Groundfish Survey (IR-IGFS).

and abundance indices, two kinds of data are given, that is, total weight or total numbers and length frequency distribution. Four surveys provide relative indices of *M. merluccius* abundance over time (Figure 1.8). The French RESSGAC surveys were conducted in the Bay of Biscay from 1978 to 2002. The EVHOE-WIBTS-Q4 surveys were carried out in the Bay of Biscay and in the Celtic Sea with a new design since 1997. The SpPGFS-WIBTS-Q4 surveys were on the Porcupine Bank since 2001. And the Irish Groundfish Surveys (IGFS-WIBTS-Q4) began in 2003 in the west of Ireland and the Celtic Sea.

The general trend of recruitment is to decline from the mid-1980s, but with high recruitments in 3 years of the last decade (Figure 1.9). The SSB was high at the start of the series (130,000 t in 1980), but later it has decreased steadily to a low level at the end of the 1990s (44,500 t in 1998). However, SSB has increased in 2012 to the highest value of the time series (277,794 t). From 2008 on, the SSB increases strongly. Mean values of fishing mortality of *M. merluccius* (average of F-at-length over lengths 15–80 cm) increased from about 0.5–0.6 per year in the late 1970s and early 1980s to about 1.0 per year during the 1990s. However,

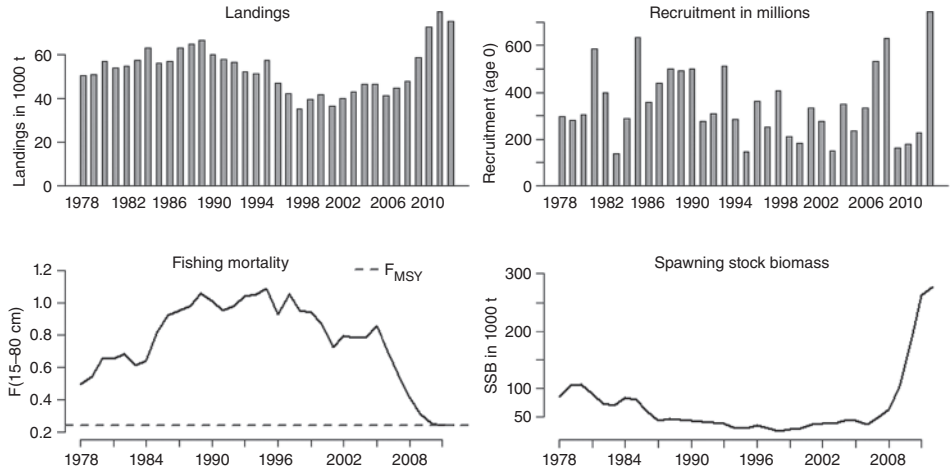

Figure 1.9 Time series of total landings (top panel, left), recruitment (top panel, right), fishing mortality (lower panel, left) and spawning stock biomass of *M. merluccius* (lower panel, right) in the northern hake stock since 1978–2012. With the exception of landings, other indicators are output in the assessment model.

from the middle of the 2000s, F of *M. merluccius* declined continuously to reach 0.24 per year in the years 2011 and 2012. The sharp increase in SSB is the direct consequence of a series of good recruitments in the middle of the 2000s and a high individual growth rate estimated by SS3, which is K=0.177 per year. It is consistent with the growth rate estimated from tagging data (De Pontual *et al*., 2006). In 2010, FMSY (fishing mortality corresponding to maximum sustainable yield) was fixed in 0.24 per year, based on F30% (fishing rate that would reduce the spawning biomass per recruit to 30% of its unfished level).

1.7.2 Southern stock

Until 2009, the southern stock of *M. merluccius* was assessed with an age-based assessment model with ages estimated from age–length keys. Since 2010, GADGET (Begley and Howell, 2004; www.hafro.is/gadget) age-length based model was used (length ranges from 1 to 130 cm and age ranges from 0 to 15+ years). Recruitment is modelled in the first and second quarters, which are the two main recruitment periods. The length at recruitment is estimated by the model following the von Bertalanffy growth function.

Landings by fishing gear are collected since 1972. Length distributions of *M. merluccius* are available since 1982. Discards data are collected regularly since 2003. The main cause of hake discards is the minimum landing size regulation enforced in 1992 (<27 cm of total length), similar to the one established for the northern stock.

Three surveys carried out in the whole stock area in autumn are used to calibrate the model. The North Spanish October groundfish survey is performed

since 1983 (except 1987), the South Spanish November groundfish survey is performed since 1997 and the Portuguese ground fish survey is carried out since 1979. Two Landing per Unit of Effort series are used to calibrate the model, that is, the Spanish A Coruña trawl series from 1994 and the Portuguese standardised trawl series from 1989.

The length composition sampling design follows a multistage stratified random scheme by quarter, harbour and gear. The W–L relationship for the whole period used is

$$W = 0.00659 * L^{3.017}$$

Maturity fractions-at-length was estimated with sex combined from sampling of Instituto Español de Oceanografía.

Model results show that recruitment (age 0 years) in *M. merluccius* is highly variable in two periods: one ranging from 40 to 120 million (mean ∼70 million fish) from the year 1982 to 2003, and the other one ranging from 60 to 160 million (mean ∼114 million fish) from the year 2004 to 2012. The SSB was very high at the beginning of the time series (∼40,000 t), then decreased to a minimum of 5,900 t in 1998 (Figure 1.10). Since then, the biomass of *M. merluccius* increased, reaching 25,392 t in the year 2013. *F* increased from the beginning of the time series ($F = 0.36$ per year in 1982), peaking at 1.18 per year in 1995, and remaining relatively stable until 2009 ($F = 0.95$ per year), but declining in recent years to 0.57 per year in 2012. As observed *F* is higher than FMSY proxy (Fmax is the fishing mortality giving maximum equilibrium yield per recruit to be 0.24 per year), the stock is considered as being overexploited. The retrospective pattern shows that, in recent years, SSB and recruitment have been overestimated, and *F* has been underestimated.

The stock recruitment data do not provide a clear basis to use any model to estimate reference points. Sensitivity analysis shows a huge impact on MSY, that is, BMSY and FMSY, when using Beverton and Holt model or Ricker model (Cerviño *et al.*, 2013). Fmax is the only accepted reference point being estimated in 2013 as 0.24 per year.

1.8 Management

1.8.1 Policy

The Common Fisheries Policy of the European Union (EU CFP) has basic common principles consistent with the extensive international agreements and policy norms. The more significant ones are the precautionary approach, PA (UNFSA, 1995), maximum sustainable yield, MSY (UNFSA, 1995) and the ecosystem approach to fisheries management (EAF) (UN WSSD, 2002).

The EU CFP, on the basis of the above-mentioned principles, sets the following basic rules for the EU management: annual TACs (given to each country based on their historical country stock catch share), the obligation of recording catches and landings, the kind of fishing gear to be used, areas to be closed from

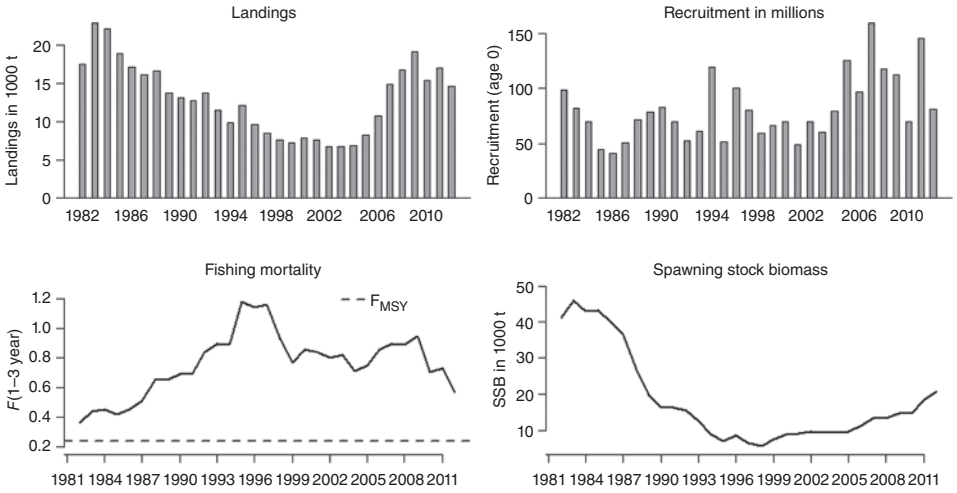

Figure 1.10 Time series of total landings (top panel, left), recruitment (top panel, right), fishing mortality (lower panel, left) and spawning stock biomass of *M. merluccius* (lower panel, right) in the southern hake stock since 1981–2012. With the exception of landings, other indicators are output in the assessment model.

fishing and minimum landing size for catch that should let small fish escape. Each EU member state is responsible for policing its own quota, using different management approaches, that is, licenses, limited entry, individual fishing quota and so on or using more restricted regulations than those defined by EC.

ICES provides fisheries management advice consistent with CFP principles of the PA and MSY, among others. The objective is well included in CFP objectives, as it is aimed to build sound scientific advice for supporting policies for long-term yields while maintaining productive fish stocks.

1.8.2 Management of European hake

1.8.2.1 Northern stock

ICES alerted about a serious risk of collapse of the northern stock of *M. merluccius* in the year 2000. Two geographical areas were defined where juvenile hakes occur in high abundance, one in the south of Ireland (the so-called 'Irish box') and the second one along the French coast (Grande Vasière). The EC agreed to establish additional measures to protect juvenile hakes. Minimum mesh sizes were introduced for towed nets and fixed gears (European Council, 1998). Additional measures were also taken to reduce the capture of juveniles of *M. merluccius* by beam trawlers and trawlers targeting *Nephrops*. Besides, control measures were strengthened, and the number of observers on board vessels targeting hake was increased.

In 2004, the EC adopted a recovery plan for the northern stock (European Council, 2004). The objective was to achieve, for two consecutive years, a level of SSB greater than Bpa (biomass precautionary approach reference point).

Bpa was estimated as 140,000 t in 2004, and the TAC was set to a level corresponding to a fishing mortality of 0.25 per year. SSB of the stock reached Bpa during two consecutive years in 2007 (ICES, 2007). Thus, in 2009, the EC communicated a proposal to replace the recovery plan for a long-term management plan (European Council, 2009; Garcia *et al.*, 2011). The objective of the plan was to achieve a fishing mortality level corresponding to MSY by 2015 in accordance with the plan of implementation (UN WSSD, 2002; European Commission, 2006). In 2010, the stock assessment was replaced, because the perception of the stock changed with the new model, and the long-term management plan proposal was no longer valid. At present, ICES advice on *M. merluccius* is based on the MSY framework (ICES, 2012).

1.8.2.2 Southern stock

The southern stock of *M. merluccius* is managed with TAC and effort regulations as well as technical measures including minimum landing size of 27 cm of total length, protected areas and minimum mesh size (European Council, 1998). A Recovery Plan for this stock was enforced in the year 2006 under the European Council Regulation, which established measures for recovery of southern hake through technical measures for the protection of juveniles of marine organisms (European Council, 2005). This plan aimed to rebuild the southern stock to within safe biological limits by decreasing fishing mortality to a maximum of 10% per year and a TAC constraint of 15%. The target F was 0.27 per year (Fmax as a proxy of FMSY set in 2005). SSB target defined in the plan was 35,000 t. Nevertheless, after the change of the assessment model in 2010, this reference was no longer considered suitable. The plan includes effort management in addition to TAC measures (European Council, 2013). Failure to enforce the plan meant that objectives of F reduction have not been achieved and F=FMSY will probably not be reached by the intended date of 2015 (STECF, 2010).

The TAC is set every year considering the harvest control rule set in the plan. National quotas for Spain, Portugal and France are shared according to the EU relative stability principle, that is, a pre-agreement about quota shares for all the countries and stocks.

Since 2005, a 10% annual reduction of fishing days at sea was applied to all vessels, although with some exclusions. In 2012, vessels that landed less than 5 t of *M. merluccius* in the year 2009 or 2010 were excluded from this reduction as well as vessels that retain less than 3% hake.

Technical measures applied to this stock are set depending on areas and gears by several national regulations. In the north of Spain, there are some areas where trawling is forbidden. These banned areas were designed not only to protect areas where juveniles grow, but also to avoid conflicts with other fishing gears. The Portuguese regulations also established a closure for trawling off the southwest coast of Portugal from December to February.

1.9 Markets

European market of *M. merluccius* has become increasingly international and global in the last decades, being precisely the origin of this fish, one of the most important attributes influencing market prices (Asche and Guillem, 2012). In the context of this global market, Spain is the largest hake (*Merluccius* species) market in the world, accounting for one half of the total European consumption of hake. According to information provided by EUROSTAT (http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database), in 2009, total weight catches of *M. merluccius* landed by 25 EU countries in total fishing areas stood at about 84,400 t, from which Spanish catches represent 37%. Of the producing countries in the Northeast Atlantic Ocean, Spain, France and the UK stand out (Amigo and Garza, 2011) being catches of *M. merluccius* of about 22,000, 17,000 and 7900 t, respectively (EUROSTAT).

Besides, Spain also receives high imports from both EU and non-EU countries due to the Spanish high demand, together with the implementation of a fishing legislation, which has been moving progressively towards the implementation of individual transferable quotas with regards to the industrial fishing in community waters (Laxe, 2006). The most important Spanish imports from non-EU countries are coming from Chile, Argentina and South Africa. The Vitoria airport located in the Basque Country (Spain) is one of the major *Merluccius* import places in Europe. The first-sale prices for fish from the most preferred origin such as Spain could be more than double compared to those for the fish from the last preferred source such as South Africa (Asche and Guillem, 2012).

The hake demand is segmented in three principal transformation levels such as fresh fish, frozen fish and frozen fillet. Prices and distribution chains differ depending on the segment. On the one hand, the fresh and chilled segment is nowadays supplied by both European production and imports. These imports reached 17,000 t in 1980/1981 and experienced a sharp drop to 0 t in 1983 until today (http://www.fao.org/fishery/statistics). On the other hand, frozen hake and frozen fillet segments are essentially supplied by imports. Frozen Argentinian *Merluccius* annual prices show a positive trend with an average value of about 1.75 US$/kg for the period 2000–2009, which represent a significant decrease compared to the fresh segment prices. However, high-quantity volatility is stated with significant quantity falls up to 40% and even 76% through 2000–2009.

The structure of Spanish *Merluccius* value chain is based on three levels. The first level concerns to the production sector itself, which supply depends on the stock status, the regulation and the fishing strategies related to fishermen behaviour (Prellezo *et al*., 2009). These authors reported a fishermen behaviour model description for the Basque trawler fleet exploiting European hake. The second level is mainly related to the wholesales (Mercas), which distribute fish to the third level, that is, to other wholesalers in other locations or to retailers

Table 1.2 *Merluccius* first-sale prices, wholesale, retail prices and gross margins

	Producer level		Wholesale level			Retail level		
Year	Price (€/kg)	Contribution to final price (%)	Price (€/kg)	Gross margin (€)	Contribution to final price (%)	Price (€/kg)	Gross margin (€)	Contribution to final price (%)
2009	5.1	31	6.87	1.77	11	16.69	9.82	59
2010	4.29	26	5.92	1.63	11	15.37	9.45	61
2011	4.4	26	5.64	1.24	8	14.64	9	61
2012	4.1	25	5.88	1.78	12	14.95	9.07	61
2013	4.18	25	5.68	1.5	10	15.25	9.57	63

Information available at the Spanish Ministry of Agriculture, Food and Environment.

(fishmongers' supermarkets, etc.), which make the hake fish available to final consumers.

The *Merluccius* market reveals the existence of high differentiated sources in the price formation along the three levels of the value chain, but in general can be considered to be highly integrated. Attending to the annual average prices, gross margins and contribution of each level to the final price, in general, the retail margins are much higher than the wholesale margins for the period 2009–2013 (Table 1.2). In particular, wholesale prices reflect an average increase of 36% with respect to the first-sale prices, going up to 150% in the case of the retail prices with respect to wholesale prices. The contribution of the producers, wholesalers and retailers to the final price to consumer is in average 27%, 11% and 62%, respectively.

1.10 Discussion

The assessment of *M. merluccius* is carried out separately for northern and southern stocks. Before 2010, both stocks were assessed using age-structured models, but analysis of tagging programs showed that age was overestimated, and therefore, nowadays both stocks are assessed using length-structured models. In the last decade, the SSB increased in both stocks. The SSB of the northern stock exceeded the historic levels of the 1980s, confirming the stock restoration. Although SSB is below historic level it is not considered to be overexploted, because there was not any reference point to SSB. But F is above Fmsy, then the stock is being overexploted. In both stocks, recruitment swings regularly, but remained at an average rate although SSB increased, which could be due to a self-regulation mechanism of the stock size.

The increase of both northern and southern European hake stocks abundances, in the decade of the 2000s, is reflected in the landings increase, with fishing mortality decreasing. Despite the significant amount of the European hake catches, it does not satisfice the high consumption level of the Spanish people. Thus, the external trade is essential, and as a consequence, the *M. merluccius* market has become more international and global, Spain being

the largest market in the world and accounting for one half of the total European human consumption.

The market prices are influenced by the origin of the fish, the transformation level of the fish and the value chain. The price of most preferred origin could be twice as much as the last preferred source. Besides, fresh fish price is significantly higher than other transformation levels' price. In general, the contribution of producers, wholesalers and retailers to the final price to consumers is in average 27%, 11% and 62%, respectively. The high level of hake imports in Spain holds due, in part, to the consumers' traditional demand and the good consumers' perception about the hake prices in the market. However, consumers have neither been traditionally able to distinguish the hake species nor the fishing technique used for catching it, which has promoted the introduction of explanatory information in the markets.

References

Álvarez, P. & Cotano, U. (2005) Growth, mortality and hatch-date distributions of European hake larvae, *Merluccius merluccius* (L.), in the Bay of Biscay. *Fisheries Research*, **76**, 379–391.

Álvarez, P., Fives, J., Motos, L. & Santos, M. (2004) Distribution and abundance of European hake *Merluccius merluccius* (L.) eggs and larvae in the North East Atlantic waters in 1995 and 1998 in relation to hydrographic conditions. *Journal of Plankton Research*, **26**, 811–826.

Álvarez, P., Motos, L., Uriarte, A. & Egaña, J. (2001) Spatial and temporal distribution of European hake, *Merluccius merluccius* (L.), eggs and larvae in relation to hydrographical conditions in the Bay of Biscay. *Fisheries Research*, **50**, 111–128.

Amigo, L. & Garza, M.D. (2011) Analysis of the *Merluccius merluccius* market chain. Estimated results for production in Galicia. *International Business and Economics Research Journal*, **10**, 123–130.

Aranda, M., Murillas, A. & Motos, L. (2006) Command and control quota-based regimes. In: Motos, L. & Wilson, D.C. (eds), *The Knowledge Base for Fisheries Management*. Elsevier, The Netherlands.

Arbault, S. & Lacroix-Boutin, N. (1969) Epoques et aires de ponte de poissons teleostés dans le Golfe de Gascogne en 1964. *Revue des Travaux de l'Institut des Peches Maritimes*, **32**, 413–476.

Asche, F. & Guillem, J. (2012) The importance of fishing method, gear and origin: the Spanish hake market. *Marine Policy*, **36**, 365–369.

Balado, M., Montse, P. & Presa, P. (2003) Influence of marine currents on the gene flow among atlantic populations of *Merluccius merluccius*. IV Simposio sobre el Margen Ibérico Atlántico, N° 19 (2b).

Begley, J. & Howell, D. (2004) An overview of Gadget, the globally applicable Area-Disaggregated General Ecosystem Toolbox. ICES CM 2004/FF: 13.

Bertalanffy, L. von (1938) A quantitative theory of organic growth. *Human Biology*, **10**, 181–213.

Bianchi, G., Carpenter, K.E., Roux, J.P., Molloy, F.J., Boyer, D. & Boyer, H.J. (1993) *FAO Species Identification Field Guide for Fishery Purposes. The Living Marine Resources of Namibia*. FAO, Rome. 250 p.

Borges, M. F., Hill, L., Mendes, H., Santos, A.M. & Salgado, M. (2004) Regime shift effects on fish community metrics measured in the West Portugal upwelling area. ICES C.M. 2004/M:11.

Brown, D.R., Leonarduzzi, E. & Machinandiarena, L. (2004) Age, growth and mortality of hake larvae (*Merluccius hubbsi*) in the north Patagonian shelf. *Scientia Marina*, **68**, 273–283.

Cabral, H.N. & Murta, A.G. (2002) The diet of blue whiting, hake, horse mackerel and mackerel off Portugal. *Journal of Applied Ichthyology*, **18**, 14–23.

Casey, J. & Pereiro, J. (1995) European hake (*M. merluccius*) in the northeast Atlantic. In: Alheit, J. & Pitcher, T.J. (eds), *Hake: Fisheries, Ecology and Markets*. Chapman and Hall, London, pp. 125–147.

Castro, J., Punzón, A., Pierce, G.J., Marín, M. & Abad, E. (2010) Identification of métiers of the Northern Spanish coastal bottom pair trawl fleet by using the partitioning method CLARA. *Fisheries Research*, **102**, 184–190.

Castro, J., Marín, M., Pierce, G.J. & Punzón, A. (2011) Identification of métiers of the Spanish set-longline fleet operating in non-Spanish European waters. *Fisheries Research*, **107**, 100–111.

Castro, J., Marín, M., Pérez, N., Pierce, G.J. & Punzón, A. (2012) Identification of métiers based on economic and biological data: the Spanish bottom otter trawl fleet operating in non-Iberian European waters. *Fisheries Research*, **125–126**, 77–86.

Castillo, A.G.F., Alvarez, P. & García-Vázquez, E. (2005) Population structure of *Merluccius merluccius* along the Iberian Peninsula coast. *ICES Journal of Marine Science*, **62**, 1699–1704.

Cerviño, S., Domínguez, R., Jardim, E., Mehault, S., Piñeiro, C. & Saborido-Rey, F. (2013) Impact of egg production and stock structure on MSY reference points. Implications for Southern hake management. *Fisheries Research*, **138**, 168–178.

Chassot, E., Rouyer, T., Trenkel, V.M. & Gascuel, D. (2008) Investigating trophic-level variability in Celtic Sea fish predators. *Journal of Fish Biology*, **73**, 763–781.

Cohen, D.M., Inada, T., Iwamoto, T. & Scialabba, N. (1990) FAO species catalogue. Vol. 10. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other Gadiform fishes known to date. *FAO Fisheries Synopsis*, **125**, 10–442.

Coombs, S.H. & Mitchell, C.E. (1982) The development rate of eggs and larvae of the hake, *Merluccius merluccius* (L.) and their distribution to the west of the British Isles. *Journal du Conseil / Conseil Permanent International pour l'Exploration de la Mer*, **40**, 119–126.

CRAMER (2012) Ecología del reclutamiento de la merluza: implicaciones sobre la gestión del recurso. REF.: CTM2010-21856-MAR.

Cury, P.M., Shin, Y.J., Planque, B. *et al.* (2008) Ecosystem oceanography for global change in fisheries. *Trends in Ecology and Evolution*, **23**, 338–346.

De Pontual, H., Bertignac, M., Battaglia, A., Bavouzet, G., Moguedet, P. & Groison, A.L. (2003) A pilot tagging experiment on European hake (*Merluccius merluccius*): methodology and preliminary results. *ICES Journal of Marine Science*, **60**, 1318–1327.

De Pontual, H., Groison, A.L. & Piñeiro, C. (2006) Evidence of underestimation of European hake growth in the Bay of Biscay, and its relationship with bias in the agreed method of age estimation. *ICES Journal of Marine Science*, **63**, 1674–1681.

De Pontual, H., Jolivet, A., Bertignac, M. & Fablet, R. (2012) Diel vertical migration of European hake *Merluccius merluccius* and associated temperature histories; insights from a pilot data-storage tagging (DST) experiment. *Journal of Fish Biology*, **81**, 728–734.

De Pontual, H., Jolivet, A., Garren, F. & Bertignac, M. (2013) New insights on European hake biology and population dynamics from a sustained tagging effort in the Bay of Biscay. *ICES Journal of Marine Science*, **70**, 1416–1428.

Díez, G., Díaz, E., Arregi, L. *et al.* (2011) Evaluación del impacto en el ciclo biológico y estructura demográfica de especies de interés ecológico y comercial después del vertido del Prestige. *Revista de Investigación Marina*, **18**, 92–133.

Domínguez-Petit, R. (2007) Study of reproductive potential of *Merluccius merluccius* in the Galician shelf. Doctoral Thesis. University of Vigo, Spain.

Domínguez-Petit, R. & Saborido Rey, F. (2010) New bioenergetic perspective of European hake (*Merluccius merluccius* L.) reproductive ecology. *Fisheries Research*, **104**, 83–88.

Dominguez-Petit, R., Korta, M., Saborido-Rey, F., Murua, H., Sainza, M. & Piñeiro, C. (2008) Changes in size at maturity of European hake Atlantic populations in relation with stock structure and environmental regimes. *Journal of Marine Systems*, **71**, 260–278.

Drouineau, H., Mahévas, S., Bertignac, M. & Duplisea, D.E. (2010) A length-structured spatially explicit model for estimating hake growth and migration rates. *ICES Journal of Marine Science*, **67**, 1697–1709.

Du Buit, M.H. (1996) Diet of hake (*Merluccius merluccius*) in the Celtic Sea. *Fisheries Research*, **28**, 381–394.

European Council (1998) Council Regulation (EC) N° 850/98 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms. *Official Journal L*, **125**, 1–36.

European Commission (2001) Commission Regulation (EC) N° 1162/2001of 14 June 2001 establishing measures for the recovery of the stock of hake in ICES sub-areas III, IV, V, VI and VII and ICES divisions VIII a, b, d, e and associated conditions for the control of activities of fishing vessels. *Official Journal L*, **159**, 4–9.

European Council (2004) Council Regulation (EC) N° 811/2004 establishing measures for the recovery of the Northern hake stock. *Official Journal of the European Union L*, **150**, 1–11.

European Council (2005) Council Regulation (EC) No. 2166/2005 establishing measures for the recovery of the Southern hake and Norway lobster stocks in the Cantabrian Sea and Western Iberian Peninsula and amending Regulation (EC) No. 850/98 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms. *Official Journal of the European Union L*, **345**, 5–10.

European Commission (2006) Communication from the Commission to the Council and the European Parliament COM (2006) 360 (final)-Implementing sustainability in EU fisheries through maximum sustainable yield {SEC(2006) 868}.

European Council (2009) Council Regulation COM (2009) 122 (final) establishing a long-term plan for the northern stock of hake and the fisheries exploiting that stock {SEC(2009)300 {SEC(2009)301}.

European Council (2013) Council Regulation (EU) No. 39/2013 of 21 January 2013 fixing for 2013 the fishing opportunities available to EU vessels for certain fish stocks

and groups of fish stocks which are not subject to international negotiations or agreements. *Official Journal of the European Union L*, **23**, 1–53.

Fariña, A.C. & Fernández, A. (1986) Datos biológicos de la merluza oeste de Irlanda. *Informes Técnicos, Instituto Español de Oceanografía*, **47**, 3–13.

Fariña, A.C., Freire, J. & González-Gurriarán, E. (1997) Demersal fish assemblages in the Galician continental shelf and upper slope (NW Spain): spatial structure and long-term changes. *Estuarine, Coastal and Shelf Science*, **44**, 435–454.

Fernandes, J.A., Irigoien, X., Goikoetxea, N. *et al.* (2010) Fish recruitment prediction using robust supervised classification methods. *Ecological Modelling*, **221**, 338–352.

Fiksen, O. & Slotte, A. (2002) Stock-environment recruitment models for Norwegian spring spawning herring (*Clupea harengus*). *Canadian Journal of Fisheries and Aquatic Sciences*, **59**, 211–217.

Garcia, D., Prellezo, R., Santurtun, M. & Arregi, I. (2011) Winners and losers of a technical change: a case study of long-term management of the Northern European Hake. *Fisheries Research*, **110**, 98–110.

Goikoetxea, N. & Irigoien, X. (2013) Links between the recruitment success of northern European hake (*Merluccius merluccius* L.) and a regime shift on the NE Atlantic continental shelf. *Fisheries Oceanography*, **22**, 459–476.

Goñi, N., Logan, J., Arrizabalaga, H., Jarry, M. & Lutcavage, M. (2011) Variability of albacore (*Thunnus alalunga*) diet in the Northeast Atlantic and Mediterranean Sea. *Marine Biology*, **158**, 1057–1073.

Guénette, S. and D. Gascuel. 2009. Considering both fishing and climate in a model of the Celtic Sea and the Bay of Biscay: what do we learn? ICES Document CM 2009/F:07.

Guichet, R. (1995) The diet of European hake (*Merluccius merluccius*) in the northern part of the Bay of Biscay. *ICES Journal of Marine Science*, **52**, 21–31.

Hewitt, D.A. & Hoenig, J.M. (2005) Comparison of two approaches to estimate natural mortality based on longevity. *Fishery Bulletin*, **103**, 433–437.

Hinder, S.L., Gravenor, M.B., Edwards, M. *et al.* (2013) Multi-decadal range changes vs. thermal adaptation for north east Atlantic oceanic copepods in the face of climate change. *Global Change Biology*, **20**, 140–146.

Hollowed, A.B. (1992) Spatial and temporal distribution of Pacific hake *Merluccius productus* larvae and estimates of survival during early life stages. *California Cooperative Oceanic Fisheries Investigations Report*, **33**, 100–123.

Houde, E.D. & Zastrow, C.E. (1993) Ecosystem-and taxon-specific dynamic and energetics properties of larval fish assemblages. *Bulletin of Marine Science*, **53**, 290–335.

Hunter, J.R., Lo, N.C.H. & Leong, R. (1985) Batch fecundity in multiple spawning fishes. In: Lasker, R. (ed),, NOAA Technical Report NMFS, 36 *An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: application to the Northern Anchovy,* Engraulis mordax, pp. 67–78.

Ibaibarriaga, L., Irigoien, X., Santos, M. *et al.* (2007) Egg and larval distributions of seven fish species in north-east Atlantic waters. *Fisheries Oceanography*, **16**, 284–293.

ICES (1991) *Report of the working group on the assessment of the stocks of hake*. ICES CM 1991/Assess: 20, 181 p.

ICES (2006) *Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2006*. ICES Advice. Books 1–106, 310 p.

ICES (2007) Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM), 8–17 May 2007, Vigo, Spain. ICES CM 2007/ACFM:21.

ICES (2008) Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM), 30 April–6 May, 2008. ICES Headquarters, Copenhagen. ICES CM 2008/ACOM:07.

ICES (2009) Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM), 5–11 May, 2009. Copenhagen. ICES CM 2009/ACOM:08.

ICES (2010a) Report of the Workshop on Age Estimation of European Hake (WKAEH), 9–13 November 2009, Vigo, Spain . ICES CM 2009/ACOM: 42.

ICES (2010b) Report of the Benchmark Workshop on Roundfish (WKROUND), 9–16 February 2010, Copenhagen, Denmark. ICES CM 2010/ACOM:36.

ICES (2012) Report of the workshop 3 on implementing the ICES FMSY framework (WKFRAME 3), 9–13 January, 2012. ICES, Headquarters. ICES CM 2012/ACOM:39.

ICES (2013) Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM), 10–16 May, 2013. ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:11A.

Jennings, S., Greenstreet, S.P.R., Hill, L., Piet, G.J., Pinnegar, J.K. & Warr, K.J. (2002) Long-term trends in the trophic structure of the North Sea fish community: evidence from stable isotope analysis, size-spectra and community metrics. *Marine Biology*, **141**, 1085–1097.

Kacher, M. (2004) Le merlu du golfe de Gascogne et de la mer Celtique: croissance, répartition spatiale et bathymétrique, écologie alimentaire et assemblages. Thèse de 3ème cycle, Universitaté du Littoral Côte d'Opale.

Kacher, M. & Amara, R. (2005) Distribution and growth of 0-group European hake in the Bay of Biscay and Celtic Sea: a spatial and inter-annual analyses. *Fisheries Research*, **71**, 373–378.

Korta, M., Domínguez-Petit, R., Murua, H. & Saborido-Rey, F. (2010a) Regional variability in reproductive traits of European hake *Merluccius merluccius* L. populations. *Fisheries Research*, **104**, 64–72.

Korta, M., Murua, H., Kurita, Y. & Kjesbu, O.S. (2010b) How are the oocytes recruited in an indeterminate fish? Applications of stereological techniques along with advanced packing density theory on European hake (*Merluccius merlucssius* L.). *Fisheries Research*, **104**, 56–63.

Koutsikopoulos, C. & Le Cann, B. (1996) Physical processes and hydrological structures related to the Bay of Biscay anchovy. *Scientia Marina*, **60**, 9–19.

Lassalle, G., Gascuel, D., Le Loc'h, F. *et al.* (2012) An ecosystem approach for the assessment of fisheries impacts on marine top-predators: the Bay of Biscay case study. *ICES Journal of Marine Science*, **69**, 925–938.

Lavin, A., Valdes, L., Sánchez, F. *et al.* (2006) The Bay of Biscay: the encountering of the ocean and the shelf. In: Robinson, A.R. & Brink, K.H. (eds), *The Sea*. Vol. **14**. NOAA, Silver Spring, Md, Chapter 24.

Laxe, F.G. (2006) Transferability of fishing rights: the Spanish case. *Marine Policy*, **30**, 379–388.

López-López, L., Preciado, I., Villamor, B. *et al.* (2012) Is juvenile anchovy a feeding resource for the demersal community in the Bay of Biscay? On the availability of pelagic prey to demersal predators. *ICES Journal of Marine Science.*, **69**, 1394–1402.

Lloris, D., Matallanas, J. & Oliver, P. (2003) Merluzas del mundo (Familia Merluccidae). Catálogo comentado e ilustrado de las merluzas conocidas. FAO Catálogo de especies para los fines de la pesca N°2.

Lucio, P., Murua, H. & Santurtun, M. (2000) Growth and reproduction of hake (*Merluccius merluccius*) in the Bay of Biscay during the period 1996–1997. *Ozeanografika*, **3**, 325–354.

Mahe, K., Amara, R., Bryckaert, T., Kacher, M. & Brylinski, J.M. (2007) Ontogenetic and spatial variation in the diet of hake (*Merluccius merluccius*) in the Bay of Biscay and the Celtic Sea. *ICES Journal of Marine Science*, **64**, 1210–1219.

Marigómez, I., Soto, M., Cancio, I., Orbea, A., Garmendia, L. & Cajaraville, M.P. (2006) Cell and tissue biomarkers in mussel and histopathology in hake and anchovy from Bay of Biscay after the prestige oil spill (Monitoring Campaign 2003). *Marine Pollution Bulletin*, **53**, 287–304.

Martin, I. (1991) A preliminary analysis of some biological aspects of hake (*M. merluccius* L. 1758) in the Bay of Biscay. ICES CM 1991/G:54. Demersal Fish Commitee.

Mason, E., Coombs, S. & Oliveira, P.B. (2006) An overview of the literature concerning the oceanography of the eastern North Atlantic region. Relatórios Cientéficos e Técnicos do IPIMAR, Série Digital, 33.

Mattiucci, S., Abuaunza, P., Ramadori, L. & Nascetti, G. (2004) Genetic identification of *Anisakis* larvae in European hake from Atlantic and Mediterranean waters for stock recognition. *Journal of Fish Biology*, **65**, 495–510.

Meiners, C.G. (2007) Importancia de la variabilidad climática en las pesquerías y biología de la merluza europea *Merluccius merluccius* (Linnaeus, 1758) de la costa Noroccidental Africana. Ph.D. Thesis, Universidad Politécnica de Cataluña.

Methot, R.D. Jr., & Wetzel, C.R. (2013) Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research*, **142**, 86–99.

Meynier, L., Pusineri, C., Spitz, J., Santos, M.B., Pierce, G.J. & Ridoux, V. (2008) Intraspecific dietary variation in the short-beaked common dolphin *Delphinus delphis* in the Bay of Biscay: importance of fat fish. *Marine Ecology Progress Series*, **354**, 277–287.

Morote, E.M.P., Olivar, A., Bozzano, F., Villate, F. & Uriarte, I. (2011) Feeding selectivity in larvae of the European hake (*Merluccius merluccius* L.) in relation to ontogeny and visual capabilities. *Marine Biology*, **158**, 1349–1361.

Motos, L., Alvarez, P. & Uriarte, A. (1998) Hake (*Merluccius merluccius* (L.)) spawning in the Bay of Biscay during winter 1995. *Oceanológica Acta*, **21**, 18.

Motos, L., Alvarez, P. & Uriarte, A. (2000) Distribution pattern of hake (*Merluccius merluccius* (L.)) eggs and larvae in relation to environmental conditions in the Bay of Biscay in winter and early spring 1995. *Ozeanografika*, **3**, 273–292.

Murua, H. (2006) Reproductive fundamentals for the estimation of egg production of the European hake, *Merluccius merluccius*, in the Bay of Biscay. PhD Thesis. Euskal Herriko Unibertsitatea – Universidad del País Vasco, Spain.

Murua, H. (2010) The biology and fisheries of European hake, *Merluccius merluccius*, in the North-East Atlantic. *Advances in Marine Biology*, **58**, 97–154.

Murua, H. & Motos, L. (2006) Reproductive strategy and spawning activity of the European hake *Merluccius merluccius* (L.) in the Bay of Biscay. *Journal of Fish Biology*, **69**, 1288–1303.

Murua, H., Motos, L. & Lucio, P. (1998) Reproductive modality and batch fecundity of the European hake (*Merluccius merluccius* L.) in the Bay of Biscay. *Californian Cooperative Oceanic Fisheries Investigation Reports*, **39**, 196–203.

Murua, H., Kraus, G., Saborido-Rey, F., Witthames, P.R., Thorsen, A. & Junquera, S. (2003) Procedures to estimate fecundity of marine fish species in relation to their reproductive strategy. *Journal of Northwest Atlantic Fishery Science*, **33**, 33–54.

Murua, H., Lucio, P., Santurtun, M. & Motos, L. (2006) Seasonal variation in egg production and batch fecundity of European hake *Merluccius merluccius* (L.) in the Bay of Biscay. *Journal of Fish Biology*, **69**, 1304–1316.

Olaso, I. (1990) Distribución y abundancia del megabentos invertebrado en fondos de la plataforma cantábrica. Informe Técnico del. Instituto Español de Oceanografía, 5.

Olaso, I., Sánchez, F. & Piñeiro, C.G. (1994) Influence of anchovy and blue whiting in the feeding of Northern Spain hake. ICES CM 1994/P:9.

OSPAR Commission (2000) *Quality Status Report 2000: Region IV Bay of Biscay and Iberian Coast OSPAR Commission*. OSPAR Commission, London.

Ottersen, G. & Sundby, S. (1995) Effects of temperature, wind and spawning stock biomass on recruitment of Arcto-Norwegian cod. *Fisheries Oceanography*, **4**, 278–292.

Parrish, R.H., Nelson, C.S. & Bakun, A. (1981) Transport mechanisms and reproductive success of fishes in the California Current. *Biology and Oceanography*, **1**, 175–203.

Pereiro, F. J., Sánchez, F. & Fontenla, J. (1991) Hake recruitment in the southern stock (Int. Council Explor. Sea Divisions VIIIc and IXa). ICES CM. 1991/G:52.

Pérez, N. & Pereiro, F.J. (1985) Aspectos de la reproducción de la merluza, *M. merluccius*, de la plataforma gallega y cantábrica. *Boletín, Instituto Español de Oceanografía*, **2**, 39–47.

Persohn, C., Lorance, P. & Trenkel, V. (2009) Habitat preferences of selected demersal fish species in the Bay of Biscay and Celtic Sea, North-East Atlantic. *Fisheries Oceanography*, **18**, 268–285.

Pingree, R.D. & Le Cann, B. (1990) Structure, strength, and seasonality of the slope current in the Bay of Biscay region. *Journal of the Marine Biological Association, UK*, **70**, 857–885.

Pingree, R.D. & Le Cann, B. (1992) Three anticyclonic slope water oceanic eddies (swoddies) in the southern Bay of Biscay in 1990. *Deep Sea Research*, **39**, 1147–1175.

Piñeiro, C. & Saínza, M. (2003) Age estimation, growth and maturity of European hake (*Merluccius merluccius* Linnaeus, 1758) from the Iberian Atlantic waters. *ICES Journal of Marine Science*, **60**, 1086–1101.

Piñeiro, C. & Saínza, M. (2010) Crecimiento de la merluza europea: ¿lento o rápido? XIII Foro dos Recursos Mariños e da Acuicultura das Rías Galegas: 129–148.

Piñeiro, C., Rey, J., De Pontual, H. & Goñi, R. (2007) Tag and recapture of European hake (*Merluccius merluccius* L.) off the Northwest Iberian Peninsula: first results support fast growth hypothesis. *Fisheries Research*, **88**, 150–154.

Piñeiro, C., Rey, J., De Pontual, H. & García, A. (2008) Growth of Northwest Iberian juveline hake estimated by combining sagital and trasversal otolith microstructure analysis. *Fisheries Research*, **93**, 173–178.

Piñeiro, C.G., Morgado, C., Saínza, M. & McCurdy, W.J. (2009) Hake age estimation: state of the art and progress towards a solution. *ICES Cooperative Research Report*, **296**.

Pita, A., Presa, P. & Pérez, M. (2010) Gene flow, multilocus assignment and genetic structuring of the European hake (*Merluccius merluccius*). *Thalassas*, **26**, 129–133.

Pita, A., Pérez, M., Cerviño, S. & Presa, P. (2011) What can gene flow and recruitment dynamics tell us about connectivity between European hake stocks in the Eastern North Atlantic? *Continental Shelf Research*, **31**, 376–387.

Pita, A., Pérez, M., Balado, M. & Presa, P. (2014) Out of the Celtic cradle: the genetic signature of European hake connectivity in South-western Europe. *Journal of Sea Research*, **93**, 09–100.

Plá, C. & Roldán, M.I. (1994) Estructura genética de la merluza europea (*Merluccius merluccius*) y su relación con la gestión pesquera. In: A. Gonzalez-Garcés & F.J. Pereiro (eds), *Estado actual de los conocimientos de las poblaciones de merluza que habitan la plataforma continental atlántica y mediterránea de la Unión Europea con especial atención a la Península Ibérica*. Publicación Privada, Vigo (Spain).

Planque, B., Beillois, P., Jegou, A.M., Lazure, P., Petitgas, P. & Puillat, I. (2003) Large-scale hydroclimatic variability in the Bay of Biscay: the 1990s in the context of inter decadal changes. *ICES Marine Science Symposia*, **219**, 61–70.

Poulard, J.C. (2001) Distribution of hake (*Merluccius merluccius*, Linnaeus, 1758) in the Bay of Biscay and the Celtic sea from the analysis of French commercial data. *Fisheries Research*, **50**, 173–187.

Preciado, I., Velasco, F. & Olaso, I. (2008) The role of pelagic fish as forage for the demersal fish community in the southern Bay of Biscay. *Journal of Marine Systems*, **72**, 407–417.

Prellezo, R., Lazkano, I., Santurtun, M. & Irioando, A. (2009) A qualitative and quantitative analysis of selection of fishing areas by Basque trawlers. *Fisheries Research*, **97**, 24–31.

Punzon, A., Hernández, C., Abad, E., Castro, J., Pérez, N. & Trujillo, V. (2010) Spanish otter trawl fisheries in the Cantabrian Sea. *ICES Journal of Marine Science*, **67**, 1604–1616.

Recasens, L., Lombarte, A., Morales-Nin, B. & Torres, G.J. (1998) Spatio-temporal variation in the population structure of the European hake in the NW Mediterranean. *Journal of Fish Biology*, **53**, 387–401.

Ríos, A.F., Pérez, F.F. & Fraga, F. (1992) Water masses in the upper and middle North Atlantic Ocean east of the Azores. *Deep-Sea Research I*, **39**, 645–658.

Roldán, M.I., García-Marín, J., Utter, F. & Plá, C. (1998) Population genetic structure of European hake, *Merluccius merluccius*. *Heredity*, **81**, 327–334.

Sánchez, F. & Gil, J. (1995) Influencia de anomalías térmicas de mesoescala sobre la distribución de peces demersales. In: Cendrero, O. & Olaso, I. (eds), *Actas del IV Coloquio Internacional de Oceanografía del Golfo de Vizcaya*. Instituto Español de Oceanografia, Santander, España.

Sánchez, F. & Gil, J. (2000) Hydrgraphic mesoscale structures and Poleward current as a determinant hake (*Merluccius merluccius*) recruitment in the southern Bay of Biscay. *ICES Journal of Marine Science*, **57**, 152–170.

Sánchez, F. & Olaso, I. (2004) Effects of fisheries on the Cantabrian Sea shelf ecosystem. *Ecological Modelling*, **172**, 151–174.

Sánchez, F., Velasco, F., Cartes, J.E. *et al.* (2006) Monitoring the Prestige oil spill impacts on some key species of the northern Iberian shelf. *Marine Pollution Bulletin*, **53**, 332–349.

Santos, M.B., German, I., Correia, D. *et al.* (2013) Long-term variation in common dolphin diet in relation to prey abundance. *Marine Ecology Progress Series*, **481**, 249–268.

Santos, M.B., Saavedra, C. & Pierce, G.J. (2014) Quantifying the predation on sardine and hake by cetaceans in the Atlantic waters of the Iberian Peninsula. Deep Sea Research Part II: Topical Studies in Oceanography. *Oceanography of the Bay of Biscay*, **106**, 232–244.

Sarano, F. (1986) Cycle ovarien du Merlu, *M. merluccius*, poisson à ponte Fractionée. *Revue des Travaux de l'Institut des Peches Maritimes*, **48**, 65–76.

Shepherd, J.G. (1999) Extended survivors analysis: an improved method for the analysis of catch-at-age data and abundance indices. *ICES Journal of Marine Science*, **56**, 584–591.

Smith, P.D.E. (1995) Development of the population biology of the Pacific hake, *Merluccius productus*. *California Cooperative Oceanic Fisheries Investigations Report*, **36**, 144–152.

Solá, A.C. & Franco, C. (1985) Contribución al estudio de ictioplancton de especies de interés comercial de la plataforma cantábrica. *Boletín Español de Oceanografía*, **2**, 1–14.

STECF (2010) Report of the Sub Group on Management Objectives and Strategies (SGMOS 10-06). Part d; Evaluation of Multi-Annual Plan for hake and Nephrops in areas VIIIc and IXa. Vigo (Spain), October 18–22.

Tanner, S.E., Vasconcelos, R.P., Cabral, H.N. & Thorrold, S.R. (2012) Testing an otolith geochemistry approach to determine population structure and movements of European hake in the northeast Atlantic Ocean and Mediterranean Sea. *Fisheries Research*, **125–126**, 198–205.

UN (1995) The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, (UNFSA). United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, A/CONF.164/CRP.8, New York, August 1995.

UN (2002) Johannesburg Declaration on Sustainable Development. World Summit on Sustainable Development, A/CONF.199/20, Chapter 1, Resolution 1, Johannesburg, September 2002.

Valdés, L., Lago de Lanzós, A., Sola, A., Franco, C., Sánchez, P. & Álvarez, P. (1996) Distribution of hake, mackerel and horse mackerel eggs and larvae in relation to geostrophic circulation in the Bay of Biscay. *ICES CM*, **S:16**.

Valencia, V. & Franco, J. (2004) Main characteristics of the water massess. In: Borja, A. & Collins, M. (eds), *Oceanography and Marine Environment of the Basque Country*. Elsevier Oceanography Series, pp. 197–226.

Valencia, V., Motos, L. & Urrutia J. (1989) Estudio de la variación temporal de la hidrografía y el plancton en la zona nerítica frente a San Sebastián. Informes Técnicos del Departamento de Agricultura y Pesca del Gobierno Vasco.

Vargas, C.G., Valenzuela, G., Núñez, S. & Arcos, D. (1996) Mortalidad natural de larvas de merluza común (*Merluccius gayi gayi*) frente a Chile centro-sur en relación a su distribución espacial y grado de agregación. *Investigaciones Marinas, Valparaíso (Chile)*, **24**, 19–30.

Velasco, F. (2007) Alimentación de la merluza europea (*M. merluccius* L.) en el mar Cantábrico. PhD Thesis, Universidad Complutense de Madrid, España.

Velasco, F. & Olaso, I. (1998) European hake *Merluccius merluccius* (L., 1758) feeding in the Cantabrian Sea: seasonal, bathymetric and length variations. *Fisheries Research*, **38**, 33–44.

Velasco, F. & Olaso, I. (2000) Hake food consumption in the Southern Bay of Biscay estimated from gastric evacuation model. ICES CM 2000/Q:11.

Woillez, M., Poulard, J.C., Rivoirard, J., Petitgas, P. & Bez, N. (2007) Indices for capturing spatial patterns and their evolution in time, with application to European hake (*Merluccius merluccius*) in the Bay of Biscay. *ICES Journal of Marine Science*, **64**, 537–550.